Optimal Location, Patient Routing, and Capacity Decisions for Endoscopy Clinical Network in Western Ontario: A Simulation-based Optimization Approach

by

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I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Thousands of Canadians die or suffer from colorectal cancer (CRC) every year. Unawareness of risk factors and the lack of sufficient screening capacity contributes to these numbers. In Ontario, CRC death rates are high, therefore, the Ministry of Health and Cancer Care Ontario and Long-Term Care have launched a population-based provincial colorectal cancer screening program. Considering that it is 92% curable if detected early, it is crucial for people to have access to screening facilities for routine screening to avoid serious consequences.

In this study, we develop a simulation-based optimization approach to find most favorable facility locations, along with the necessary number of staff, equipment, and dedicated rooms within each facility to provide three endoscopy screening services: Colonoscopy, Gastroscopy, and Flexible-Sigmoidoscopy. The model and its results may provide insights to policy makers in facilitating public access to endoscopy screening resources in Ontario.

We developed a discrete-event simulation model to mimic the parallel processes within an endoscopy clinic in order to estimate the associated utilizations of resources and average waiting times of all patient groups. The simulation model is used to iteratively test the desired number of doctors, nurses, and rooms within the facility for a given demand rate. Then, we integrated the simulation model with a search-based approximate-optimization algorithm which searches different sets of facility locations to open as well as capacity levels to allocate in each location, and estimate the expected total cost. The aim of the algorithm is to provide a location capacity decision that minimizes the expected total cost given that expected waiting times are within acceptable limits.

We propose three heuristic methods to find the desired number of new facilities to open, and their location. We test the proposed methodology on data from Western Ontario under different conditions.

Keywords: Health Care Delivery, Simulation-based Optimization, Location-allocation Analysis, Discrete-event Simulation, Cancer Screening, Colonoscopy, Flexible-sigmoidoscopy, Gastroscopy, Simulated Annealing, Greedy Heuristic.

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Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

Endoscopy is a nonsurgical procedure that uses an endoscope to screen internal organs along the digestive tract of patients who have reflux, rectal bleeding, stomach pain, ulcers, gastritis, difficult swallowing, diarrhea, and other digestive problems. An endoscope is a flexible tube with a light and attached camera used to take picture of the digestive tract to be examined by a doctor or a surgeon. Endoscopy clinics play a critical role in the prevention and early detection of colorectal cancers.

In 2011, approximately 8,900 Canadians died because of colorectal cancer, which makes it the second leading cause of cancer death in Canada. The Canadian Cancer Society reports that, after prostate, lung, and breast cancer, colorectal cancer is fourth most commonly diagnosed cancer in Canada [1].

In 2014, patients diagnosed with colorectal cancer will reach the 24,400 mark in Canada, which is 13% of all estimated new cancer cases. These patients include 13,500 men and 10,800 women among which 5,100 men and 4,200 women will die from colorectal cancer. In total, 9,300 Canadian lives will be lost because of colorectal cancer. On average, every day in Canada, 67 colorectal cancer cases will be detected and 26 lives will be lost [2] (See Table 1.1).

Category	Males	Females
New Cases	13,500	10,800
Incidence rate (for every 100,000 people)	59	40
Deaths	5,100	4,200
Death rate (for every 100,000 people)	22	14
5-years relative survival (estimated for 2006-2008)	64%	65%

Table 1.1 Estimated Canadian colorectal cancer statistics (www.cancer.ca 2014)

It is estimated that if 80% of Canadians aged above 50 were screened, 10,000 to 15,000 death could be prevented in the next 10 years. Fecal occult blood tests (FOBT), flexible-sigmoidoscopies or colonoscopies can be used for the diagnosis of disease. If cancer is detected early, it is 92% curable (SEER). Although the overall five-year survival rate for CRC is around 64%, in case of late diagnoses it may spread to other organs (metastasize) causing the five-years survival rate to drop for 12% (SEER 2012).

Beginning with the invention of the first flexible endoscope in the late 1960s, endoscopy of the upper and lower gastrointestinal (GI) tract brought the diagnosis and treatment of esophagus, stomach, duodenum, terminal ileum and colon disorder to a new level. It is reported that flexible sigmoidoscopy, colonoscopy and esophagogastroduodenoscopy (gastroscopy) are among the most widely used endoscopy procedure for screening the GI tract [3].

The American College of Physicians recommended that every person above age 50 should get screened by either a stool-based test, flexible sigmoidoscopy or colonoscopy to prevent CRC at its early phase, and stop screening after age 75 or in adults with a life expectancy of less than 10 years [4].

Flexible sigmoidoscopy is a routine outpatient procedure to screen gastrointestinal symptoms, such as rectal bleeding and abdominal pain [5]. It used to examine one third of inner lining of the lower large intestine, while colonoscopy is used to screen the entire colon. In addition, colonoscopy allows the specialist to remove the adenomatous polyps, a small benign growth on the inner surface of the colon which may lead to colorectal cancer. On the other hand, gastroscopy is used to screen the upper digestive tract: the esophagus, stomach and duodenum which are beyond the scope of flexible sigmoidoscopy and colonoscopy.

Because endoscopy clinics play a key role in colorectal cancer prevention and early detection as well as the follow-up of gastro-intestinal symptoms, enhancing their capacity and increasing their accessibility is critical for the welfare of society. As part of this project, we investigate answers to the following strategic questions:

- Is it cost effective to open new clinics in counties that do not currently have endoscopy services?
- What is the optimum number of resources (doctors, nurses, operation and PR rooms) in existing clinics to satisfy all the demand of Western Ontario for a desired waiting time?
- Where should new clinics be opened and what is the priority order?
- What should the new capacity be for open clinics and in that case what utilization rate to target?

Although, endoscopy clinics can be both in hospital or private clinics, in this study, we have considered only existing private endoscopy clinics in Western Ontario. Hospitals with the same services are ignored as a result of the Ontario government's new plan to cut endoscopy services from hospitals and to move them to private clinics [6].

In this thesis, we propose a simulation-based optimization approach for the optimal location and allocation of endoscopy clinics within Western Ontario to cover the demand of the region while keeping wait times under a certain threshold. We introduce and compare three heuristic methods to find the best demand coverage with minimum cost, based on stochastic discrete-event simulation of screening facilities. It is assumed that each facility has three main endoscopy screening processes, namely colonoscopy, flexible sigmoidoscopy and gastroscopy (screening procedure of the digestive track: esophagus, stomach, and the beginning of the small intestine).

1.1 Literature Review

1.1.1 Surveys and Models on Endoscopy Clinics

Hilsden (2004) examined the use of endoscopy in Alberta, Canada [3]. They examined three endoscopy procedures: gastroscopy, colonoscopy, and sigmoidoscopy and they concluded that during 1994-2001, performed screenings increased by 39%, 147% and decreased 6% respectively. They also found that, for youngsters below 19, the colonoscopy rate is very low, but over time it increases and reaches its peak in the 65-75 age group. Gastroscopy and flexible sigmoidoscopy rates gradually increase through the life span. The rates are maximum in the oldest age group, 74 and above.

Denton et al. (2006) evaluated different staffing scenarios of endoscopy surgical suite by using simulated annealing based on a Monte-Carlo simulation [7]. They investigated answers to strategic and operation questions, and tried to find the appropriate number of operating rooms, best surgeon to operation rooms ratio, optimal scheduling of arrivals and so on. The project focused on colorectal screening at the Mayo Clinic.

Schultz et al. (2007) conducted a population-based study about the provision of large bowel endoscopy services in Ontario [8]. They calculated the number of flexible-sigmoidoscopies and colonoscopuies performed per 10,000 persons by region between

April 1, 2001, and March 31, 2002 and reported that 172,108 colonoscopies and 43,400 flexible sigmoidoscopies were performed in Ontario for all age groups.

Hilsden et al. (2007) studied providers of gastrointestinal endoscopy in Canada and analyzed provincial and regional differences in endoscopy providers [9]. By reviewing 100 colonoscopies and gastroscopies performed by 1444 physicians, they concluded that 53% of colonoscopies and 59% of gastroscopies were provided by Gastroenterologists. However in rural and smaller urban areas surgeons were the main providers.

Berg et al. (2009) assessed the resource allocation of colonoscopy facilities for optimal utilization by using discrete-event simulation of colonoscopy suites with a data set of 4024 patients in 2006 [10]. They assumed a constant number of procedure rooms and endoscopists, and all arrivals are deterministic. They examined five different number of procedure rooms per endoscopist to find the maximum number of patients that can be served within a day, the mean utilization of procedure rooms, and the mean utilization of endoscopist per day. They concluded that 2 procedure rooms per endoscopist is an upper bound beyond which increasing room number does not increase patient throughput, but will decrease the utilization.

Joustra et al. (2010) integrated a discrete-event simulation with integer programming to reduce access times of an endoscopy department [11]. First, the integer program is to minimize the number of attendants and resident physicians involved in a week by re-allocating the procedures in each week. Then, the simulation is used to find access times and double booking percentages. If access time is too high or double booking is above 3%, they reallocate the procedures to meet the requirements, and update the weekly schedule. They assumed that the number of procedure rooms, surgeons and doctors is constant. In addition, they did not consider the location of the services, which is one of the differences from this research.

Erenay et al. (2014) considered static and dynamic risk factors such as gender, age, and history of CRC and used a POMDP model to develop an analytical framework for optimizing colonoscopy screening policies for prevention of CRC [12]. Güneş et al, (2014) examined the allocation of limited resources capacity of colonoscopy screening service to improve health outcomes [13].

1.1.2 Location Allocation

In the literature, there are also studies that cover both location and capacity decision related to health care facilities. Griffin et al. (2006) proposed an optimization model which is a variant of the Maximal Covering Location Problem (MCLP) to determine where the new Community Health Centers (CHCs) should be located and which services they should have [14]. The objective was to maximize demand coverage while considering budget and capacity constraints. They introduced four distance level parameters (0.25, 0.5, 0.75, and 1.0) which represent maximum percentage of the certain demand point willing to go other facilities regarding to distance between demand point and service location.

Mahar et al. (2011) investigated how pooling specialized services such as magnetic resonance imagining (MRI), transplant, and neonatal intensive care multi-hospital networks can affect cost reduction [15]. Their model considered a subset of the existing hospitals to determine how many and which hospitals should deliver a specialized service by considering both patient service and financial aspect. Their model found the stable state of queues without considering the upper bound to the waiting times within the facility. Rather they find the solution that covers all demands with certain proportions.

Shariff et al. (2012) proposed a generic algorithm heuristic to solve maximum coverage location problem (MCLP) with limited capacity within the allowable distance requirement by the Malaysian government [16]. They used the linear optimization model developed by Pirkul and Schilling (1991) where the objective is to maximize population assigned to open facilities [17]. They used two ways to improve the existing coverage: adding more resources to the existing facilities, and opening new ones. They assumed however, deterministic demand which is different from the current work.

There are some location models that integrate waiting time in facility location and capacity allocation decisions. Elhedhli (2005) proposed a linearization method for service systems design to solve a facility location problem with immobile servers, stochastic demand and congestion [18]. Open facilities are modeled as multiple M/M/1 queues. The model is a nonlinear mixed-integer programming (MIP) which minimizes total facility opening, travelling and expected waiting costs.

Similarly, Berman and Drezner (2007) and Aboolian et al. (2008) modeled a service system design problem [19-20]. Aboloolian et al. (2008) associated a cost to the used time and modeled the problem as minimization of total travel time plus average waiting time spent for all patients, and assumed facilities are fixed. They developed three heuristics to solve the problem, a greedy dropping, a tabu search, and branch and bound ε-optima method.

Rahmati et al. (2014) developed a bi-objective model for the facility location-allocation problem with immobile servers and stochastic demand as an M/M/1/K queue system [21]. The proposed model contains two minimization problems: minimization of total setup cost of the facility and capacity cost, and minimization of waiting and expected travelling time.

Research on location-allocation problems in health care includes Daskin and Dean (2004), Fulton et al. (2010) for locating mobile military hospitals, and Côté et al. (2007) for locating traumatic brain injury treatment units, Erdemir et al. (2010) and Huang et al.

(2010) for optimized location for emergency medical services, Ndiaye and Alfares (2008), Tiwari and Heese (2009), Wu et al. (2007) for hospital location selection [22-29].

1.1.3 Simulation in Health Care

Simulation in health care has a long history. Roberts and England (1981) reported that simulation is used for modeling emergency and non-emergency admissions in 1962 [30]. Simulation studies in health care include but are not limited to capacity allocation and hospital bed planning, outpatient clinics, emergency room modeling, resource allocation and utilization of resources, scheduling, flow of patients and waiting times and others, Benneyan (1997) [31].

VanBerkel and Blake (2007) examined alternative ways to improve resource utilization and capacity planning in general surgery by using a discrete-event simulation model in ARENA to achieve wait time reduction in general surgery [32]. As a result of the simulation they discovered that the system bottleneck was bed resources. They redistributed beds between sites to meet emergency operational requirements with a minimum number of available beds.

Taheri et al. (2012) built a discrete-event simulation model of the endoscopy unit of Duke University Medical Center (DUMC) to test different strategies in order to find the minimum recovery nurse requirement [33]. The authors included seven endoscopy procedures with eight preparation bays, eight procedure rooms, twelve recovery bays, four preparation and four recovery nurses. They recommended modification in patient scheduling to reduce nurse overtime hours.

Taheri et al. (2013) modified the previous model account for different set of rooms with only three main endoscopy procedures: Colonoscopy, Gastroscopy, and Flexible-sigmoidoscopy [34]. Although they separated preparation and recovery bays and nurses, in practice an empty slot in preparation can be used for recovery, or recovery nurse can replace preparation nurse and vice versa. They used Simio Simulation Software to model their system. In contrast we built our own algorithm in MatLab that enables us to model the difference explained above and which to make the simulation more realistic.

Marmor et al. (2013) used a discrete-event simulation model to approximate the minimum number of beds to meet the demand at Mayo Clinic cardiovascular surgery. The model is also used to investigate various surgery schedules [35].

Wang et al. (2013) developed a simulation model to study work flow in the hospital emergency department room [36]. They considered more detailed procedures and developed a method for the calculation of length of stay for analyzing system-theoretic properties.

Zhang and Puterman (2013) developed a discrete-event simulation model to determine the yearly capacity levels for long-term care (LTC) [37]. They used simulation based optimization to find the optimum number of LCD beds in the next 10-20 years with keeping the waiting time under the desired level. Zhang et al. (2012) is similar to Zhang and Puterman (2013) where the objective is to have a minimum number of long-term care beds that provide at least 85% of clients' admission to the care center within 30 days [38].

Recently, Tako et al. (2014) developed a discrete-event simulation model in Simul8 to prioritize the planning investment for allocating new capacity to improve service quality and meet future demands in obesity care service [39]. The main goal of the project was to investigate how an 18-week target can be reached in the foreseeable future without adding capacity, only by recruiting new surgeons and physicians.

Besides the works mentioned earlier, several simulation models integrated with simulation-based optimization were applied to facility layout, facility location, and scheduling problems. The literature includes but is not limited to Leung and Cheung

(2000), Karabakal et al. (2000), De Angelis et al. (2003), Byrne and Hossain (2005), Acar et al. (2007) and others [40-44].

1.2 Structure of the Thesis

Following this introductory chapter, Chapter 2 presents the problem formulation, the process flow, and system parameters. In Chapter 3, we describe the discrete-event simulation model mimicking the processes in a given endoscopy clinic to evaluate the performances of location and capacity decisions. Chapter 4 introduces the heuristics we used to find approximately optimal solutions for this facility location and capacity allocation problem. Implementation and performance of the proposed methodology to improve the endoscopy clinic network design in Western Ontario is described in Chapter 5. Finally, conclusions are given in Chapter 6.

Chapter 2

Problem Formulation

To formulate the problem under study, we define indices $i \in \{1,2, \ldots I\}$ and $j \in \{1,2, \ldots J\}$ to represent demand locations (DL_i) and facility locations (FL_j), respectively. At each demand location DL_i there are particular demands for colonoscopy, gastroscopy, and flexible sigmoidoscopy. To serve demand, up to Y new facilities can open among the possible facility locations where each facility (clinic) is capable of providing the three types of service as fast as the available resources within the facility allows.

We refer to colonoscopy, gastroscopy, and flexible sigmoidoscopy operations as OP1, OP2, and OP3, respectively. Resources include, colonoscopy doctors (OP1 doctors), gastroscopy doctors (OP2 doctors), flexible sigmoidoscopy doctors (OP3 doctors), nurses, beds of preparation and recovery rooms (PR rooms), and equipment of each screening as well as OP1, OP2, and OP3 rooms. We assume that doctors and operation rooms of each screening are dedicated; however, nurses and PR rooms are common. Note that we do not reduce the facilities into $M/M/1$ or $G/G/1$ queuing systems. Each facility is a complex queuing network established by the components described above.

We also define the following decision variables:

$$y_j = \begin{cases} 1 & if\ a\ facility\ at\ FL_j\ is\ opened \\ 0 & otherwise \end{cases}$$

$$x_{ij} = \begin{cases} 1 & if\ location\ i's\ demand\ DL_i\ is\ allocated\ to\ FL_j \\ 0 & otherwise \end{cases}$$

d_{tj}: $\quad$ $number\ of\ type\ t\ doctors\ at\ FL_j$ $\quad$ $t \in \{1,2,3\}$ $\quad j \in \{1,2, \ldots J\}$

r_{tj}: $number\ of\ type\ t\ operation\ rooms\ at\ FL_j$ $t \in \{1,2,3\}$ $j \in \{1,2, \dots J\}$

n_j: $number\ of\ nurses\ at\ FL_j$ $j \in \{1,2, \dots J\}$

p_j: $number\ of\ PR\ beds\ at\ FL_j$ $j \in \{1,2, \dots J\}$

<u>*And the following parameters:*</u>

c_{ij}: $unit\ access\ cost\ from\ from\ DL_i\ to\ FL_j$ $i \in \{1,2, \dots I\}$ $j \in \{1,2, \dots J\}$

λ_i: $total\ demand\ rate\ of\ DL_i$ $i \in \{1,2, \dots I\}$

f_j: $fixed\ cost\ of\ opening\ facility\ at\ FL_j$ $j \in \{1,2, \dots J\}$

α_{tj}: $cost\ of\ recuiting\ type\ t\ doctor\ at\ FL_j$ $t \in \{1,2,3\}$ $j \in \{1,2, \dots J\}$

β_{tj}: $cost\ of\ opening\ type\ t\ operation\ room\ at\ FL_j$ $t \in \{1,2,3\}$ $j \in \{1,2, \dots J\}$

γ_j: $cost\ of\ recuiting\ nurse\ at\ FL_j$ $j \in \{1,2, \dots J\}$

θ_{tj}: $cost\ of\ assigning\ PR\ beds\ at\ FL_j$ $j \in \{1,2, \dots J\}$

Y: $Maximum\ number\ of\ facilities\ allowed\ to\ open$

$\widehat{W}$: $Maximum\ allowed\ waiting\ time\ for\ patients\ waiting\ for\ screening$

Note that $d_{tj}, r_{tj}, n_j, and\ p_j$ are simulation input and W_k is simulation output. W_k ($k = 1, 2, \dots, 9$) is the total waiting time of patient type k where:

- k = 1, 2, 3 represents "New Patient" of type 1, 2, 3.
- k = 4, 5, 6 represents "Operation Patient" of type 1, 2, 3.
- k = 7, 8, 9 represents "Follow-up patient" of type 1, 2, 3.

The patient types are explained in detail in Section 2.1. After patients first come to the endoscopy clinic to meet with a doctor for consultation (New Patients), these patients will come back for the operations (Operation Patients) with probability $p_1 = 98\%$. There is $p_2 = 95\%$ probability that an operated patient will come back one more time for post-operation consultation (Follow-up Patient).

In addition, we have made a simplifying assumption for assigning each demand location to the nearest open facility, which can be modeled as:

$$\sum_j x_{ij} = 1 \qquad \forall i \in \{1,2,\ldots I\}$$

$$x_{ij} \le y_j \qquad \forall i \in \{1,2,\ldots I\}\ \forall j \in \{1,2,\ldots J\}$$

$$\sum_{\varphi \in \mathrm{J}} c_{i\varphi} x_{i\varphi} \le (c_{ij} - M) y_j + M \qquad \forall i \in \{1,2,\ldots I\}\ \forall j \in \{1,2,\ldots J\}$$

As a result of the constraint above, if y_j= 0 the constraint is not effective because M is large. If y_j=1, patient i cannot be assigned to a facility which has greater access cost than the facility j, otherwise, the constraint will be violated. So demand is assigned to the facility with minimum unit access cost. An example of location-allocation is presented in Figure 1.1.

The generic simulation-based optimization model can be represented as follows:

$$\text{Min} \sum_i \sum_j c_{ij}\lambda_i x_{ij} + \sum_j f_j y_j + \sum_t \sum_j \left(\boldsymbol{d_{tj}}\alpha_{tj} y_j + \boldsymbol{r_{tj}}\beta_{tj} y_j\right) + \sum_j \left(\gamma_j \boldsymbol{n_j} y_j + \theta_j \boldsymbol{p_j} y_j\right) \qquad (1)$$

Subject to

$$\sum_j y_j \le Y \qquad \forall j \in \{1,2,\ldots J\} \qquad (2)$$

$$\sum_j x_{ij} = 1 \qquad \forall i \in \{1,2,\ldots I\} \qquad (3)$$

$$x_{ij} \le y_j \qquad \forall i \in \{1,2,\ldots I\}\ \forall j \in \{1,2,\ldots J\} \qquad (4)$$

$$\sum_{\varphi \in J} c_{i\varphi} x_{i\varphi} \le (c_{ij} - M) y_j + M \qquad \forall i \in \{1,2, \dots I\} \; \forall j \in \{1,2, \dots J\} \tag{5}$$

$$W_k \le \widehat{W} \qquad \forall k \in \{1,2, \dots, 9\} \tag{6}$$

$$y_j \in \{0,1\}, x_{ij} \in \{0,1\} \qquad \forall i \in \{1,2, \dots I\} \; \forall j \in \{1,2, \dots J\}$$

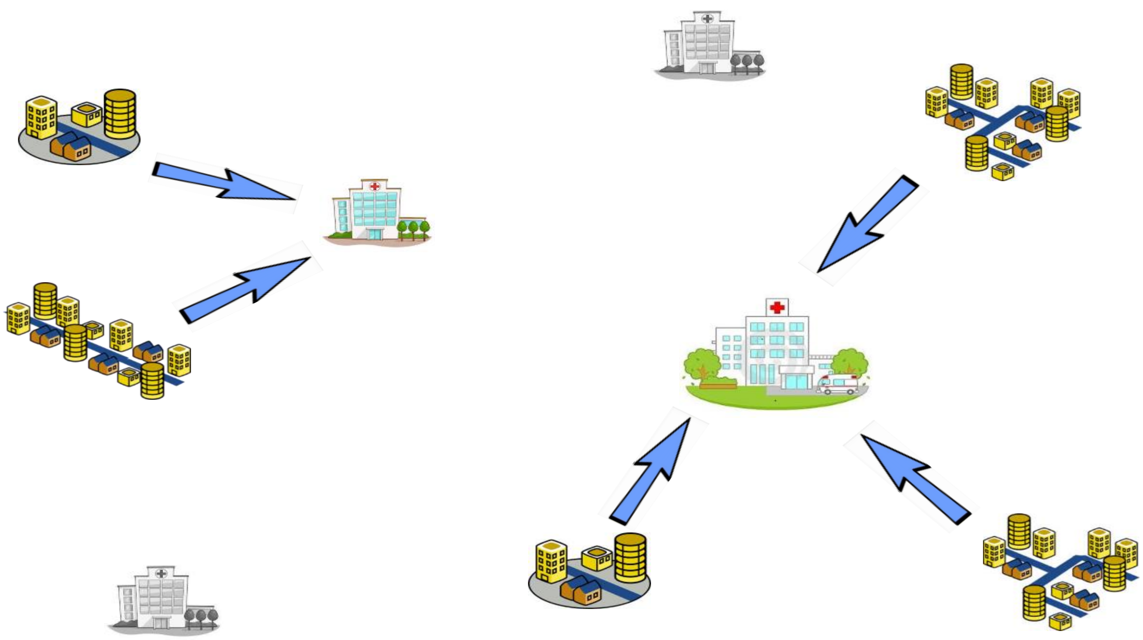

Figure 1.1 Sample location-allocations of demand to open facilities.

The first term of the objective function is the unit access cost, the second term is for the facility opening cost, and the remaining terms are the cost of allocated resources, which will be discussed in the next section. Constraint (2) ensures that total open facilities doesn't exceed a curtain threshold (Y). Constraints (3) and (4) provide that, every demand location is assigned to only one open facility. Constraint (5) ensures that each demand is assigned to the closest open facility while constraint (6) enforces that the average waiting time for each patient (or each patient type at each open location) doesn't exceed the given upper bound.

2.1 Conceptual Model and the Process Flow in the Simulation Model

As mentioned above, the simulation model represents 3 parallel endoscopy screening procedures in each clinic. Each type of screening is assumed to have 3 different patient groups, "New Patients", "Operation Patients", and "Follow-up Patients". Figure 2.1 depicts the visited sections of the clinic and underwent processes for all patient types.

When a patient visits a facility for the first time, he/she is considered to be a "New Patient". New Patients first visit the reception to fill in the initial forms in the general waiting area. Then he/she joins the queue for consultation with the doctor. The doctor(s) meet new and follow-up patients in consulting rooms or conduct the screening procedures (and surgical operations such as polypectomy or biopsy if necessary) in the operating rooms. The priority rule is first come first served (FIFS). After the consultation, each new patient decides whether to have an operation or not.

In future visits, the patient is considered as an operation patient. Figure 2.2 presents the process flow of an operation patient. The patient arrives with certain probability depending on population size of the county, which is derived from literature and national statistics (See Section 2.2). After informing the reception upon arrival, he/she joins the queue for check-up prior to the operation, which usually consists of a health check, medication, heart rate and blood pressure check, and HIV test. The patient proceeds to check-up only if there is at least one PR room and a check-up nurse, available.

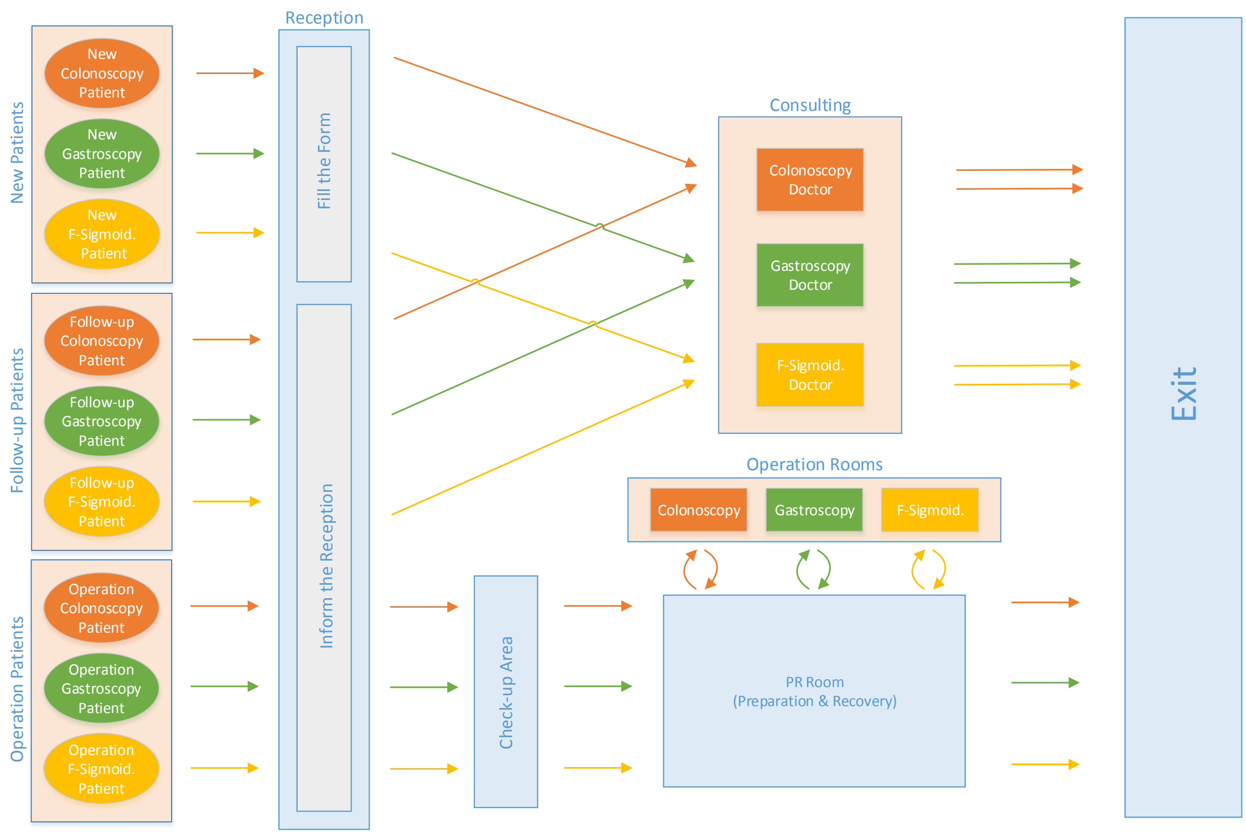

Figure 2.1 Locations visited by patients of all type

After the check-up, patients proceed to the PR room for preparation and one nurse attends them for instructions and help. Preparations involve activities such as removing clothing and sedation. After that, patients wait on a portable bed in the PR room to be transferred to the operation room for screening. The operation rooms are assumed to be dedicated to a specific operation which is conducted with the help of any nurse and one of the doctors with the necessary expertise. If there is no available operation room when a patient is ready, the first available doctor waits to conduct the operation in the first available operation room.

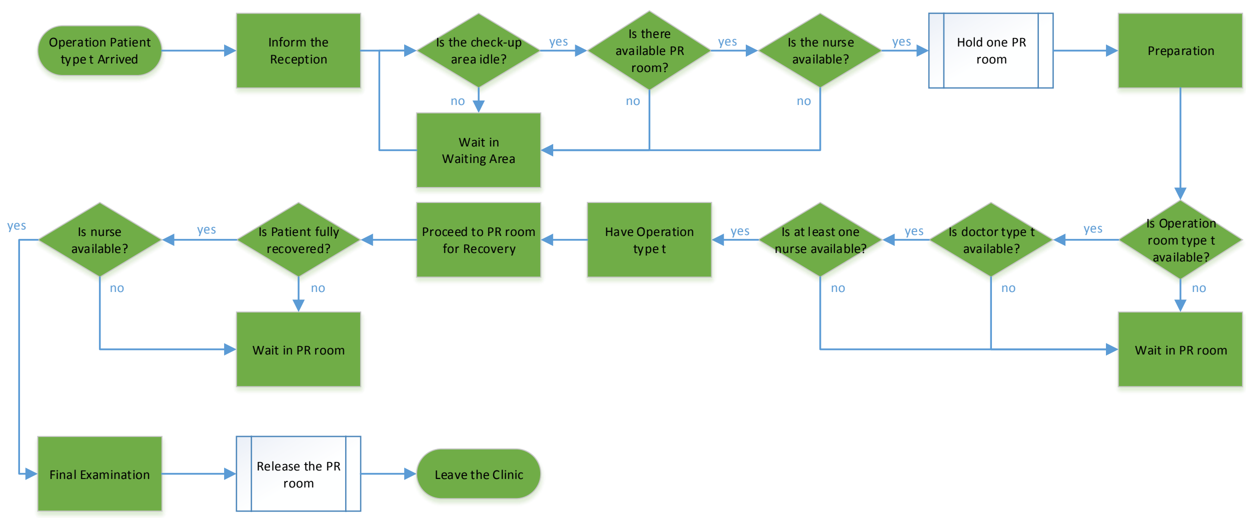

Figure 2.2 The process flow of operation patient

When a patient proceeds to his/her operation, the PR room he/she used is held until he/she comes back. After the operation, the patient is returned to that PR room while being unconscious due to sedation with the help of a nurse, and remains there until he/she fully recovers. Before leaving the clinic, patient waits for the first available nurse for a final check-up and to fill out the necessary forms.

After the operation, operation patients usually return for a post-operation consultation. We refer to such patients as follow-up patients who need to meet with a doctor to explain the results of the screening and to provide information about his/her health condition if the screening discovered an abnormality. The consultation time of such patients depends on the level of the abnormality found during screening. Detailed location-based process flow charts of new, operation, and follow-up patients are given in Appendix A.

The process flows for the three operations (colonoscopy, gastroscopy, and sigmoidoscopy) are similar, but with different parameters (arrivals, procedure, recovery and so on). It can be seen from Figure 2.1 that the flows of the three types of patients intersect at the reception, check-up, and PR rooms where common nurses manage the procedures. This is the main reason why these three procedures can't be simulated independently. A layout based process flow of operation patients is given in Figure 2.3. The process flow of new and follow-up patients is given in Appendix A.

2.1.1 Assumptions

The following assumptions are made in the simulation based optimization model:

1. The ratio of population by age groups is similar in all counties
2. Each facility has only three endoscopy screening processes: colonoscopy, gastroscopy, and flexible-sigmoidoscopy.
3. Check-up capacity is constant, which is only one at a time. These processes can be done by any of the nurses in the clinic.
4. Colonoscopy and gastroscopy have similar consulting times.
5. Doctors and operation rooms are dedicated but nurses and PR rooms can be utilized by all three endoscopy procedures.
6. For each procedure one nurse should accompany the doctor during the operation.
7. Each demand location will be assigned to the nearest open facility.
8. Each county can have a maximum one facility. It will be placed in the center of the county.
9. None of the existing facilities can be closed
10. No preemption, resource failure, limits on queues, or queue departure.

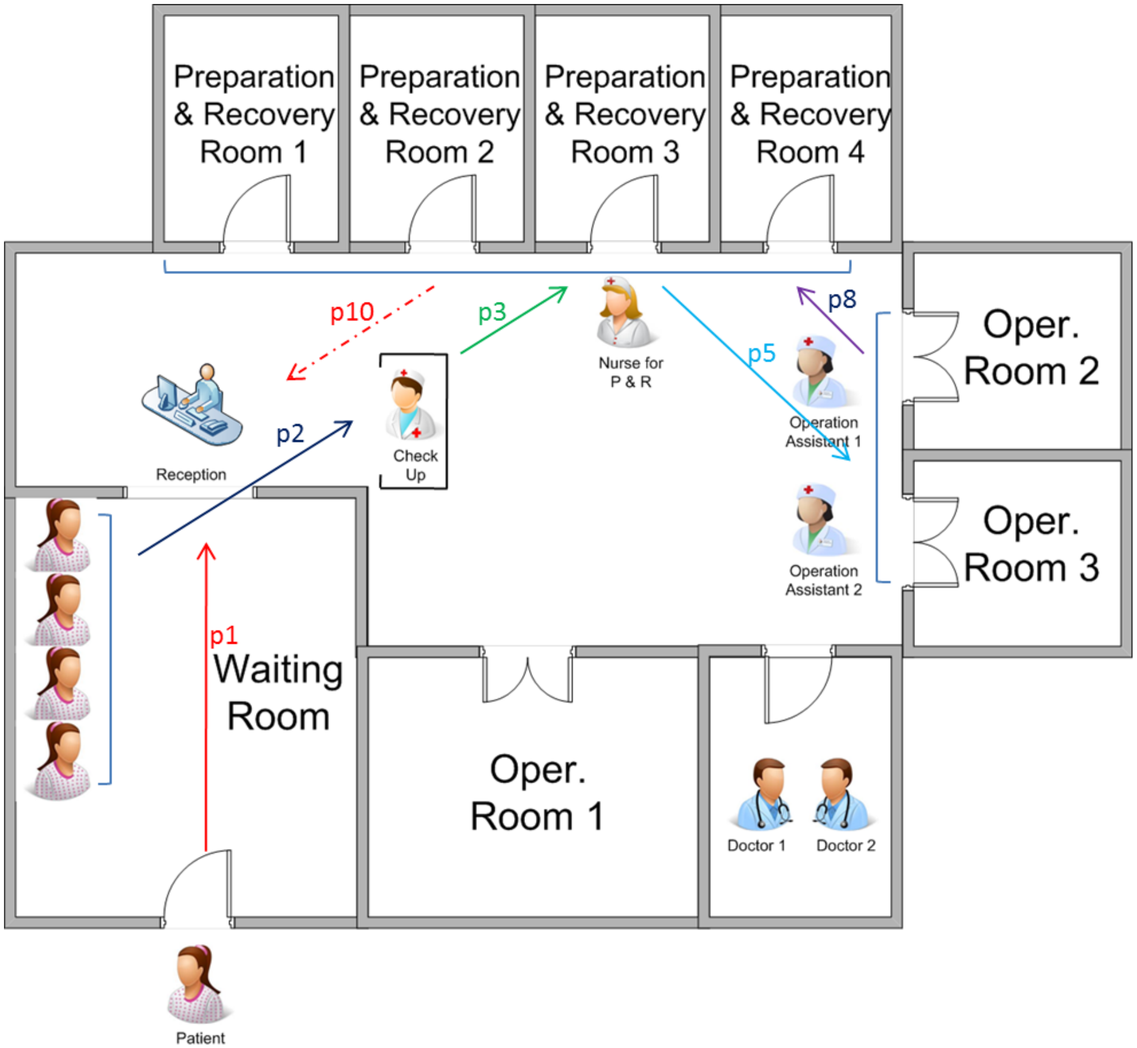

Figure 2.3 Layout based process flow of incoming operation patient

Procedure for
<u>Operation Patient:</u>

✓**p1** – Inform Reception for arrival
✓**q1** - Wait for check up
✓**p2** - Go to meet with check up nurse
✓**q2** - Wait for P&R Nurse & for available room
✓**p3** - Go to P&R room with P&R Nurse and get prepared for Operation
✓**q3** - Wait for the available Op. room & doctor & Op. Assistant
✓**p4** - When Doctor available, he spent some time reading patient file
✓**p5** - Got to operation room with the help of Operation Assistant
✓**p6** - Have an Operation
✓**p7** - After operation Doctor spent some time for filling paperwork
✓**p8** - Go to P&R room with Op. Assistant
✓**p9** - Wait for recovery
✓**q4** - Wait for P&R nurse return for final check
✓**p8** – Final check by P&R nurse
✓**p10** - Leave the hospital

2.2 Input Parameters

2.2.1 Arrival Rates

It is obvious that the number of incoming patients (demand) mainly depends on population size. We have already mentioned that the eligible age group for colonoscopy is between 50 and 74 years old. In 2014, the Canadian total population is estimated to be 35,540,400 (http:www.statcan.gc.ca). The proportions of age groups are demonstrated in Figure 2.4.

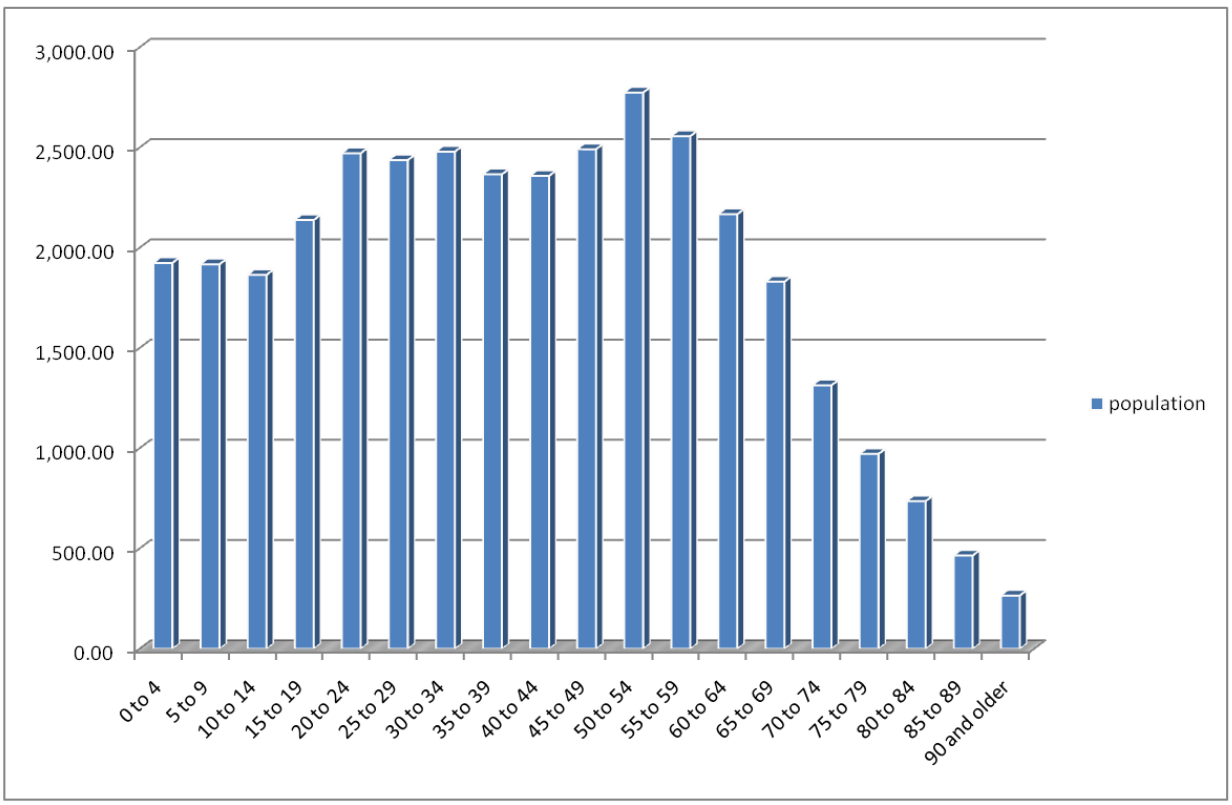

Figure 2.4 Canadian Population by Age Groups (www.statcan.gc.ca)

It can be calculated that the ratio of eligible population to Canadian total population is 29.9%, which implies that an average 29.9% patients are expected to come for colonoscopy screening once in for every 10 years according to the American Cancer Society [45].

Schultz et al. (2007) reported that between 2001-2002, the average colonoscopy rate in Ontario was 385.7 per 10,000 people ranging between 286.8 and 463.1. Our estimate is 299 per 10,000 patients is in this range (See Table 2.1 for comparison). Theoretically, our calculation reflects the best case scenario where all eligible people come for screening according to the guidelines. However, our results are lower than those estimated by Schultz et al. (2007) because many people start screening earlier than age 50 and clinicians usually recommend more frequent screening than the guidelines. In addition, our estimation method ignores the diagnostic and follow-up colonoscopy procedures which are often more frequent than every 10-year screening.

	Colonoscopy ratio (μ) per year	Observed min	Observed max
Schultz et al. (2007)	0.0386	0.0287	0.0463
Current Project	0.03	-	-

Table 2.1 Comparison between the best (all demand covered) case and existing colonoscopy arrival population ratio

We use our estimate for the colonoscopy arrival rates. We derive the estimates for the other procedures by using the ratios between gastroscopy and colonoscopy (75%) and sigmoidoscopy and colonoscopy (20%) from Hilsden et al. (2007) and Shultz et al.

(2007), respectively. Both numbers are derived for the procedures conducted by specialists in Canada. The estimated annual procedure rates are reported in Table 2.2.

Counties	Population	Colonoscopy Arrivals	Gastroscopy Arrivals	Flexible-Sigmoidoscopy Arrivals
Bruce	66,102	2551.5	1913.7	513.6
Grey	92,568	3573.1	2679.8	719.3
Dufferin	56,881	2195.6	1646.7	442.0
Wellington	208,360	8042.7	6032.0	1619.0
Huron	59,100	2281.3	1710.9	459.2
Perth	75,112	2899.3	2174.5	583.6
Waterloo	507,096	19573.9	14680.4	3940.1
Hamilton	519,949	20070.0	15052.5	4040.0
Brant	136,035	5251.0	3938.2	1057.0
Haldmiand	44,876	1732.2	1299.2	348.7
Niagara	431,346	16650.0	12487.5	3351.6
Norfolk	63,175	2438.6	1828.9	490.9
Elgin	87,461	3376.0	2532.0	679.6
Chatham-Kent	103,671	4001.7	3001.3	805.5
Essex	388,782	15007.0	11255.2	3020.8
Lambiton	124,623	4810.4	3607.8	968.3
Middlexex	439,151	16951.2	12713.4	3412.2
Oxford	105,719	4080.8	3060.6	821.4

Table 2.2 Population and total demand per year for endoscopy procedures in Western Ontario Counties

2.2.2 Processes Time and Distribution

We have used previous studies and expert opinions to find the necessary process duration distribution parameters as presented in Table 2.3. Consulting times are estimated based on expert opinion reflecting the current practice in the Medical School at the University of Wisconsin-Madison (Interview with Dr. Adnan Said, Jan 2015). Follow-up consulting times depend on the findings of the colonoscopy. We derived the ratio of benign findings, adenomatous polyps, and advanced lesions (cancer, villous adenoma, or lesions with high-grade dysplasia) as 62.5%, 27%, 10.5% (Lieberman et. 2000 [46]). As colonoscopy has higher accuracy (94% [47]) than flexible sigmodoscopy (75% Schoen et al., 2012 [48]) the ratios are adjusted as 68%, 23.7%, 8.4% in flexible sigmoidoscopy. We assumed that colonoscopy and gastroscopy consulting times are similar due to the lack of data in gastroscopy results. Most of the time patients are unconscious during the operation because of sedation. As sedation is applied for all procedure, the recovery time is to wake up and get ready for departure.

Services	**Patient Type**	**Staff**	**Location**	**Duration (min)**	**Referances**
Registiration	np1 np2 np3	Receptionist	Entrance	Exponensional mean=12.5	Expert opinion
Consulting	np1	Doctor type 1	Examination & Consulting room	for Benign exponential, mean=13.5; for Adenomas exponential, mean=12.5; for Malignan exponential, mean=45	Expert opinion
	np2	Doctor type 2			
	np3	Doctor type 3			
	fp1	Doctor type 1			
	fp2	Doctor type 2			
	fp3	Doctor type 3			
Check-up	op1 op2 op3	Nurse	Check-up Area	Exponential, mean=5	Assumption
Preperation	op1 op2 op3	Nurse	PR room	Empirical, mean = 14.63, std = 7.24	Berg et al.
Procedure	op1	Doctor type 1 Nurse	Op. room type 1	*Lognormal + 3, mean = 23.55, std =7.24	Berg et al.
	op2	Doctor type 2 Nurse	Op. room type 2	*Gamma (1.83, 2.16) + 1	Taheri et al.
	op3	Doctor type 3 Nurse	Op. room type 3	*Gamma (1.83, 2.16) + 1	Taheri et al.
Recovery	op1	-	PR room	Gamma (3.08, 8.95) + 16	Taheri et al.
	op2	-	PR room	Gamma (1.7, 6.3) + 14	
	op3	-	PR room	Gamma (12, 1.71) + 29	
Final Check-up	op1 op2 op3	nurse	PR room	Exponensional mean=12.5	Expert opinion

Table 2.3 Process times and distributions, (*) process times can be changed if bleeding occurs

2.2.3 Costs Parameters

In this thesis, we only consider facility opening costs, staff salaries, and unit access costs. We do not consider the cost of providing each service for each customer as that cost is constant assuming that all patients will be eventually served.

Facility opening costs include: procedure room cost, PR room cost, check-up area and other area costs (sterile room, reception, washrooms, and so on [49]), and equipment cost. As a base case, we assigned one procedure room for each endoscopy procedure and four PR rooms in every open clinic. In the simulation, if excessive waiting times occur, the algorithm will increase the number of rooms.

There is an official minimum area requirement for procedure rooms, recovery rooms, and sanitary rooms in clinics, regulated by the Canadian government. To find the facility opening cost, we have multiplied the minimum required area with the average meter square cost required for construction of regional hospitals ($5569.5 CAD) given in the International Construction Cost Survey, 2012 [50]. It is found that the base case total cost is $ 1,295,800 CAD. See Table 2.4 for the cost of rooms.

	Required min. Area sq feet (sq. meter)	**Min Area Cost (1 sq.m = 5569.5)**
Colonoscopy Procedure Room	200 (19)	$105,820.50
Gastroscopy Procedure Room	200 (19)	$105,820.50
F-Sigmoid. Procedure Room	200 (19)	$105,820.50
PR Room	70 (6.5)	$144,807*
Sterile Room	250 (23.23)	$129,379.50
Check-up (examination)	80 (7.43)	$41,381.40
Others (lobby,reception, coridor etc)	1560 (145)	$807,577.50
Base Case Total Cost	**2560(239.16)**	**$1,295,799.90**

Table 2.4 Cost of clinic area, (*) base case has 4 PR rooms (dch.georgia.gov)

Equipment cost is the cost of screening and surgery apertures and PR beds. Staff costs are the yearly salaries of gastroenterologists and nurses, which can be found online at www.hmbendoscopy.com and http://jobstat.net.

Unit access cost is equal to the distance (km) between DL_i and FL_j multiplied with transportation cost per km (τ) which we set to \$0.45 CAD based on the travel reimbursement rate of the University of Waterloo/Policy 31, for i.e., the unit access cost is: $c_{ij} = d_{ij} * \tau \qquad \forall i \in \{1,2, \ldots I\} \;\; \forall j \in \{1,2, \ldots J\}$.

Evaluating the performance of the model for different values of τ and facility opening costs can provide insights on the efficiency of opening a new clinic. Varying these parameters will reflect the settings in other counties where the balance between these costs may vary depending on transportation' cost, the cost of living, etc. See Appendix A for distance between Western Ontario counties.

Chapter 3

Solution Methodology

To solve the model of Chapter 2 efficiently, a fast simulation model mimicking the processes in a given endoscopy clinic is needed. We should be able to change the inputs variables and parameters automatically to compute and compare a large number of different scenarios. For that reason, we built our own simulation model in MATLAB 2014a. MATLAB is more flexible compared to the other simulation package programs such as Arena, Simul8, and Promodel using which moving from one scenario to another may not be done as efficiently as desired.

The proposed simulation model runs with 33 inputs (arrival rates, number of resources, consultation and procedure durations, preparation and recovery time, etc..) and provides 35 different outputs such as average waiting time of all 9 different arrivals and utilization rate of doctors, nurses, PR and procedure rooms, and number of served and non-served patients of all type.

The execution time for the simulation of 1,000,000 patients (number of patients seen in 25-years in most counties) is 70 seconds, which proves the effectiveness of the coding logic and structure. The first 10% of running time is considered as a warm-up period, none of the performance measures were taken during this time interval. Because of the long execution time, the simulation results remain same, eliminating the need for multiple replications of the simulation.

3.2 The Coding Structure

The following step-wise pseudo algorithm describes the logic followed in the proposed simulation model. A more detailed pseudo code is given in Appendix B.

Step1: Receive all input parameters for simulation, which include:

- inter-arrival time for new, operational, and follow up patients of type 1,2,3
- registration time (Filling out the form)
- check-up time
- preparation time for screening
- consultation time for new and follow-up of type 1,2,3 doctors
- procedure time for type 1,2, 3 screening
- recovery time after type 1,2, 3 procedure
- final check-up time after recovery
- number of type 1,2,3 doctors inside the system
- number of the nurses
- number of PR rooms
- number of type 1,2,3 operation rooms

Step 2: For a given run time, the simulation model generates all next arrival times for all 9 patient types and stores them in arrays NP_1, NP_2, NP_3, F_1, F_2, F_3, OP_1, OP_2, OP_3. NP_i, F_1, and OP_i refers to new patient queue, follow-up patient queue, operation patient queue for type I patients, respectively.

Step 3: All three types of new patients go through registration depending on the availability of the receptionist and the arrival time of each patients. The registration completion times of patients are stored in 3 different arrays.

Step 4: Beside the previous 9 arrival time arrays, 9 new arrays are introduced for all waiting queues inside the network for the preparation queue (WP_1, WP_2, WP_3), operation queue (WOP_1, WOP_2, WOP_3), and final check-up queue (W_N_1, W_N_2, W_N_3).

Step 5: With the given number of nurses, PR rooms, type 1-2-3 doctors and operation rooms generate arrays of same size with initially all zero elements and stores next available time in these arrays as the system receives input patients.

Step 6: An array called EVENT LIST is created to record the first elements (smallest) of all 18 arrays in order of NP_1, NP_2, NP_3, F_1, F_2, F_3, OP_1, OP_2, OP_3, WP_1, WP_2, WP_3, WOP_1, WOP_2, WOP_3, W_N_1, W_N_2, W_N_3. Then among them the element with minimum value its index is found.

If index=1, 2, 3, 4, 5, 6.

1. Update the first available doctor of same type
2. Update the corresponding arrival (one of NP_1, NP_2, NP_3, F_1, F_2, F_3, OP_1, OP_2, OP_3) queue, by deleting first element

If index =7, 8, 9.

1. Update the first available nurse by adding preparation time
2. Update WP queue
3. Update the corresponding arrival queue

If index=10, 11, 12.

1. Update the first available nurse
2. Hold the first available PR room
3. Update WOP queue
4. Update WP queue

If index=13, 14, 15.

1. Update the first available doctor of same type
2. Update the first available operation room of same type
3. Update the first available nurse
4. Update WOP queue
5. Update W_N queue

If index=16, 17, 18.

1. Update the first available nurse
2. Update W_N queue
3. Release the PR room

Step 7: All performance measures are calculated. Note that based on the initially defined warm-up period (10% of total run time), the warm-up period is excluded and all performance measures are taken after that time interval.

Step 8: Report the performance measures:

- Utilizations of type 1,2,3 doctors
- Utilizations of type 1,2,3 operation rooms
- Utilization of PR room
- Utilization of nurses
- Average waiting time of all 9 different arrivals
- Total number of served of 9 different patient groups
- Total number of non-served of 9 different patient groups

3.2.1 Special Conditions

We have mentioned that when a patient is received in a PR room, that room is considered busy until the patient leaves. To satisfy this condition, we have introduced a variable to store the number of occupied PR rooms. If all are occupied, we simply change 3 elements (number 10, 11, and 12) inside “EVENT LIST” with a big M to avoid them to be chosen as the next event.

3.2.2 Allocating Resources in the Simulation Model

The simulation of each endoscopy clinic starts from a base case, where we have one doctor and an operation room for each process, two nurses, and 4 preparation and recovery rooms.

One of the constraints we have in our model is to keep waiting times under a threshold. It can be achieved solely by assigning large numbers of doctors, nurses, operation and PR rooms; however it will increase the workforce cost in the objective function.

In order to identify resource to increase we seek the resource with the maximum utilization rate, and increase it by one unit and repeat the process until the waiting times are below the particular threshold. This approach may reach the optimal configuration if all the processes were executed by independent servers. However, in this simulation, PR rooms are visited twice and nurses are utilized in five processes (check-up, preparation, recovery, final check-up and operation) and each doctor serves each of the three patient types.

If the approach explained above is applied, eventually the result reached can provide the set of resources where the system is stable and waiting times are in range, but it is not necessarily the optimal solution. To remedy this, an extension is added to the capacity allocation algorithm to decrease the resources which have minimum utilization step-by-step while guaranteeing compliance with the expected waiting time constraint. This way, we test if the same level of service quality can be reached with fewer resources.

The effect of the added decreasing algorithm can be observed in Chapter 5, Table 5.2-5.3-5.4.

3.2.3 Pre-Generated Random Variables

As part of the greedy adding heuristics, the initial step is to open a single facility which will serve the demand of all eighteen counties. In that case, the inter-arrival times are very small and lots of random variables are generated to simulate process and waiting times. Therefore, twenty different distribution functions are used in the simulation and together more than 243,000,000 random numbers are generated to run the simulation for one year. To reduce the CPU time, random numbers used in the case where the arrivals are at its peak (only one facility for 18 counties) are saved and reused in simulating the other configurations. As a result, the number of random number generation is reduced to around 23,900,000 and the simulation algorithm become two times faster. This idea is also applied to other heuristics to increase the run time.

3.3 Verification

We begin verification by comparing our simulation model with a M/M/1 queuing system. For this purpose, we set our model parameters for a particular endoscopy clinic to reduce it to an M/M/1 setting (i.e., same type of patients, only operations take time, other process times are equal to zero) and calculate the average and total waiting time. We then compared them with the following closed form formulation where λ is the arrival rate, μ is the service rate, L_q is the average waiting time in the queue, and L_s is the average waiting time in system.

$$L_q = \frac{\lambda^2}{\mu(\mu-\lambda)} \qquad\qquad L_s = \frac{\lambda}{\mu-\lambda}.$$

We observe that our simulation results are very close to those from the close-form expressions. In order to verify our simulation model without reducing it to a simple queuing system, we built a representative model using Arena software. For the comparisons between the Arena model and our simulation model in MATLAB, we simulated endoscopy clinics with the same parameters for some base and extreme cases (with scarce and plentiful resources). MATLAB and Arena results matched well for all configurations.

Chapter 4

Simulation Optimization

In order to solve the location-allocation problem defined in Section 2, where the performance of each location-allocation policy is determined via discrete-event simulation, we need efficient search based optimization methods. This is because evaluating all possible location and allocation policies is computationally intractable.

We propose two heuristics, Greedy Adding (GA) and Simulated Annealing (SA), to solve the problem iteratively. At each iteration, the search mechanism aims to identify the location, in which a new endoscopy clinic is open. When a candidate location is selected, the demand is redistributed among the open facilities and the simulation is run to optimize the capacity variables for each facility. The proposed simulation-based optimization approaches are explained in detail below.

4.1 The Greedy Adding Heuristic

The Greedy Adding heuristic starts from the minimum number of open facilities and at each iteration it finds the most suitable facility to add to the set of open facilities. The steps of GA are following:

Step 1. Open facility number j (initially j=1) and assign all patients from all locations to that facility.

Step 1.1: Assign the minimum number of each resource and run the simulation. If there are too few resources, the clinic will be eventually overloaded and waiting times will increase sharply after the warm-up period. In this case, increase the number of all involved staff and resources to serve this patient by one, and re-run the simulation. Continue this process until waiting times reach a steady state.

Step 1.2: If all waiting times ($\boldsymbol{W_k}$) are below the given threshold, proceed to Step 1.3. Otherwise find the excessive waiting time.

- If *k*=1, 4, 7, increase the resources among "PR room (p_j)", "nurse (n_j)", and "doctor type 1 (d_{1j})", "op-room type 1 (r_{1j})" which has the highest utilization.
- If *k*=2, 5, 8, increase the resources among "PR room (p_j)", "nurse (n_j)", and "doctor type 2 (d_{2j})", "op-room type 2 (r_{2j})" which has the highest utilization.
- If *k*=3, 6, 9, increase the resources among "PR room (p_j)", "nurse (n_j)", and "doctor type 3 (d_{3j})", "op-room type 3 (r_{3j})" which has the highest utilization.

Step 1.3: Change facility number ($j = j + 1$) and go to Step 1 for every possible facility.

Step 1.4: Among the examined open facilities choose the one which has the minimum objective value (see Equation #1).

Step 2: Add one more open facility to the set of open facilities and repeat steps 1.1, 1.2, 1.3, 1.4. Repeat step 2 until all facilities are open. If number of allowed facilities (Y) is reached, stop.

Note that if the number of allowed open facilities (Y) is more than half of possible facilities ($Y > \frac{n}{2}$), in order to decrease the computational time, it is reasonable to use a

"Greedy Dropping Heuristic". It starts with all facilities being open and closes the facility with the maximum contribution to objective function gradually, one at a time. If it reaches Y number of open facilities and the objective value is not improved in further steps, the algorithm is terminated; otherwise it continues to decrease the objective value by closing facilities.

4.2 The Simulated Annealing Heuristic

The Simulated Annealing heuristic starts from randomly chosen Y open facilities as an initial solution. It, then, examines the neighboring solutions by closing one and opening one new facility. If the solution found is better it updates the set of open facilities. Otherwise the solution is updated with a certain probability. In the beginning, the probability is set high but is reduced gradually to limit the movement to lower quality solutions. The steps of SA are as follows:

Initialization: Set Z (max number of iteration), t (initial temperature), α (temperature reduction coefficient), randomly open Y number of facilities.

Step 1: Randomly select one of the location from set of open locations, and one location among unopen locations. Then swich these two locations. After that:

> Step 1.1: Run simulations for each open location with min resources. If waiting time is congested, increase the resource capacity by one which has a higher utilization rate. (Similar to GA Step 1.1)
>
> Step 1.2: If all waiting times ($\boldsymbol{W_k}$) are below the given threshold proceed to Step 2. Otherwise find the excessive waiting time.
>
> - If *k*=1, 4, 7, increase the resources among "PR room (p_j)", "nurse (n_j)", and "doctor type 1 (d_{1j})", "op-room type 1 (r_{1j})" which has highest utilization.

- If k=2, 5, 8, increase the resources among "PR room (p_j)", "nurse (n_j)", and "doctor type 2 (d_{2j})", "op-room type 2 (r_{2j})" which has highest utilization.
- If k=3, 6, 9, increase the resources among "PR room (p_j)", "nurse (n_j)", and "doctor type 3 (d_{3j})", "op-room type 3 (r_{3j})" which has highest utilization.

Step 2: Calculate the objective value (See Equation #1) and compare it with the previous one.

- If $obj.v.^{new} \leq obj.v.^{old}$ replace the open set of facilities with new one, otherwise replace with the probability of $e^{-\Delta/t_z}$ ($\Delta = obj.v.^{new} - obj.v.^{old}$) and update temperature ($t_{z+1} = \alpha t_z$).

Step 3: If max number of iteration (Z) is reached terminate, otherwise go to Step 1.

4.3 Combination of GA and SA Heuristics

The Greedy adding heuristic is very fast to find a solution. However, because of the methodology it follows, it is possible that the solution found by GA may get stuck at a local minimum. On the other hand, the SA heuristic described in Section 4.3 starts from a randomly chosen initial solution which affects the final solution found by SA.

In order to find a better solution we propose to start the SA heuristic from the solution found by the GA heuristic. As described above, the logic behind the SA heuristic is to switch to a solution which may not be better than the previous one. Therefore, the combination GA and SA (which will be referred as GA+SA) may explore other local regions and may find a global optimal solution.

4.4 Number of Simulation Function Calls in GA and Total Enumeration

Another way to find the optimal solution is through total enumeration, which in this research means to look all the possible ways of opening facilities and allocating capacity. In the Greedy Adding heuristic, we start from one open facility and then increase the number of open facilities by one. Therefore, the number of simulation function calls for Greed Adding Heuristic is less than or equal to: $1 + 2 + \cdots + Y = Y * \frac{Y+1}{2}$

In our case, where we consider 18 counties in Ontario, the number of simulation calls is 171 where the GA heuristic takes approximately 6 hours of CPU time with i7 processor and 12GB RAM computer settings. Note that a single "simulation function" call includes multiple simulation runs starting from the base case, and the number of total simulation runs depend on the arrival rates.

However if we run the simulation for all the combinations, the number of simulation calls will be: $C(Y,1) + 2 * C(Y,2) + 3 * C(Y,3) + \cdots + Y * C(Y,Y)$ where $C(n,k)$ is the number of combinations of choosing k elements from n.

For 18 locations the number of simulation calls though total enumeration 2,359,296. Considering the ratio between simulation calls and CPU execution time, the amount of time total enumeration would takes is 9.5 years in the same computer. Therefore, total enumeration is not a viable option.

Chapter 5

Implementation and Testing

We test the proposed simulation-optimization model on data from Western Ontario, see Figure 5.1. Without loss of generality, we assume that every county can have a maximum of one facility. Basically, we find the overall endoscopy clinic capacity in each county considering a central location to provide it. In reality, the assigned capacity can be distributed among more than one clinic in each county; however, we assigned a single central location in each region for simplicity.

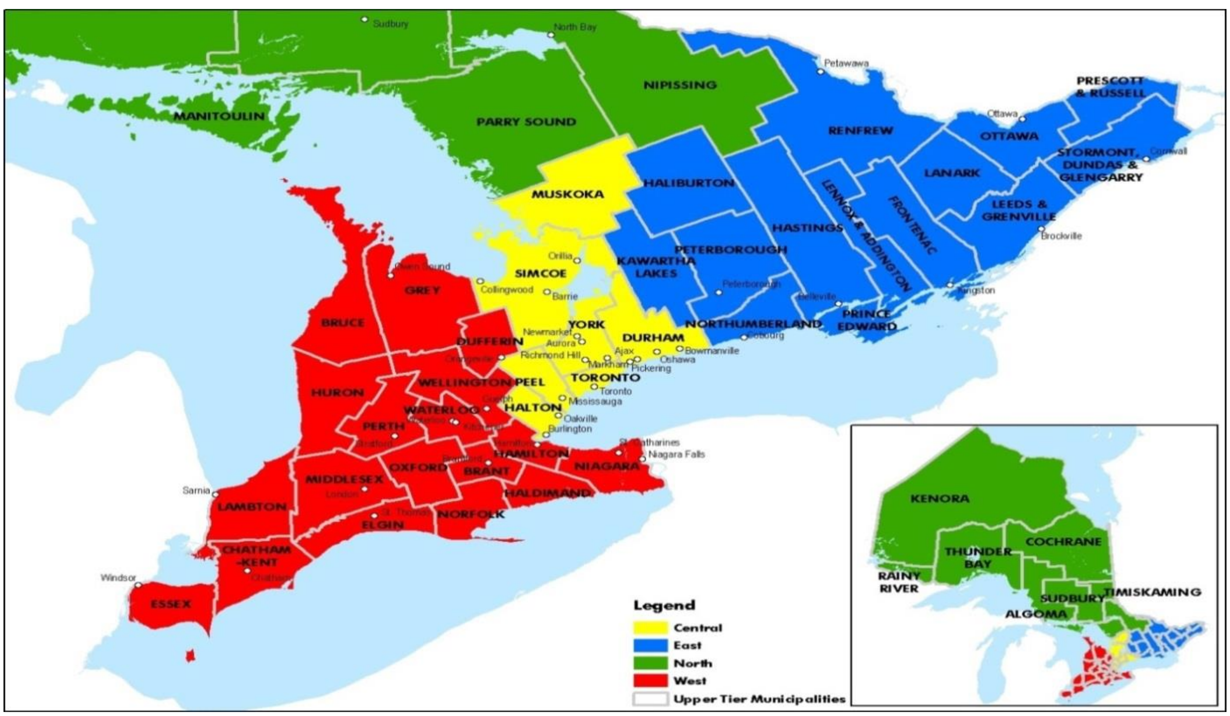

Figure 5.1 Map of The Province of Ontario. Red area represents Western Ontario (www.billavista.com)

County populations are used to find the demand and arrival rate of patients. Existing facilities are found via web search and integrated into the model with the assumption that none of the existing facilities can be closed (See Table 5.1).

	Counties	Population	Existing Endoscopy Clinic?
1	Bruce	66,102	no
2	Grey	92,568	no
3	Dufferin	56,881	no
4	Wellington	208,360	no
5	Huron	59,100	no
6	Perth	75,112	no
7	Waterloo	507,096	yes
8	Hamilton	519,949	yes
9	Brant	136,035	no
10	Haldimand	44,876	no
11	Niagara	431,346	yes
12	Norfolk	63,175	no
13	Elgin	87,461	no
14	Chatham-Kent	103,671	yes (new)
15	Essex	388,782	yes
16	Lambton	124,623	no
17	Middlesex	439,151	no
18	Oxford	105,719	no

Table 5.1 Population of counties and open private endoscopy clinics

In order to prevent and early detect colorectal cancer, everyone between age 50-74 is recommended to undergo colonoscopy screening once in every ten years. To find the arrival rate, we first determine the percentage of population who are eligible for colonoscopy screening. Canadian statistics show that the 50-74 age group represents 29.9% of the Canadian population [2]. By considering that everyone within this age group will come for a screening once every ten years, we conclude that a county's yearly demand for colonoscopy screening is:

$$DL_i = population_i * \frac{29.9\%}{10} \qquad i = 1, 2, \ldots, I.$$

To find the arrival rate of gastroscopy and flexible-sigmoidoscopy screening, we multiply the colonoscopy arrival rate with the reported ratios of gastroscopy to colonoscopy and flexible-sigmoidoscopy to colonoscopy screening in Canada from the literature ([8-9]).

To calculate unit access cost, we assumed that unit access cost is proportional to the distance between counties i.e. $c_{ij} = d_{ij} * \tau \qquad \forall i \in \{1,2,\ldots I\} \;\; \forall j \in \{1,2,\ldots J\}$ where d_{ij} is distance between county i and j and τ is price associated with distance (See Appendix A).

Other parameters like preparation time, recovery time, check-up time, screening procedure time, PR bed cost, equipment cost for each screening type, cost of recruiting nurses and doctors were found from the literature and from data available online. See Section 3 for details.

5.1 Simulation Results

Currently, endoscopy services are provided by the existing private clinics and five hospitals in Western Ontario. Since the hospital websites do not provide detailed information for the existence of endoscopy clinics and due to new regulations, only existing private clinics are considered in this research.

We divide the total demand between those five private clinics (based on the minimum distance principle) and determine the required resources in each facility to comply with the waiting time, see Table 5.2.

Initially, we start with a scarce level of resources and increase them gradually till a stable state is reached with the average service time constraint is satisfied (First Stable State Solution). After that, we conducted another search to see whether any of the resource variables can be decreased to reach the desired steady-state level of service with less capacity (Final Solution).

In the Table 5.2-5.4, the 12th column represents the number of patients received by each simulated clinic in a year. Also the average flow time of operation patients is given note that received operation patients utilize more resources than others and this causes a bottleneck. Flow time is the difference between patient arrival (to the waiting area which holds limited seats) and departure time.

Facilty Locations	*Interrarrival Time (min) NP1, NP2, NP3 OP1, OP2, OP3 FP1, FP2, FP3*	*Improvement after stable state*	**Necessary Recources**								*Number of Patients (Average Flow Time for Operation Patients)*	*Fixed Cost Access Cost Handling Cost CPU time*
			Colonoscopy Doctor(s) [util.]	*Gastroscopy Doctor(s) [util.]*	*Flexible-S. Doctor(s) [util.]*	*Nurses [util.]*	*PR rooms [util.]*	*Procedure Room(s) type 1 [util.]*	*Procedure Room(s) type 2 [util.]*	*Procedure Room(s) type 3 [util.]*		
Waterloo County (Location #7)	11.81, 15.75, 59.1 12.4, 16.6, 62.2 12.7, 16.9, 63.4	*First Stable State*	7 [0.74]	4 [0.75]	4 [0.20]	9 [0.88]	20 [0.83]	4 [0.69]	4 [0.30]	4 0.08]	**250685 (120.6 min)**	**11,164,158 23,239,300 14,377,000 12205 sec**
		Final Solution	**7 [0.74]**	**4 [0.75]**	**2 [0.40]**	**9 [0.86]**	**16 [0.98]**	**4 [0.67]**	**3 [0.39]**	**1 [0.31]**		
Hamilton County (Location #8	15.7, 20.9, 78.3 16.5, 22, 82.4 16.8, 22.4, 84.1	*First Stable State*	5 [0.78]	3 [0.75]	3 [0.20]	7 [0.84]	13 [0.96]	3 [0.69]	3 [0.30]	3 [0.08]	**39472 (126.2 min)**	
		Final Solution	**5 [0.78]**	**3 [0.75]**	**1 [0.59]**	**7 [0.84]**	**13 [0.96]**	**3 [0.69]**	**3 [0.30]**	**1 [0.23]**		
Niagara County (Location #11)	31.6, 42.1, 157.8 33.2, 44.3, 166.1 33.9, 45.2, 169.5	*First Stable State*	3 [0.64]	2 [0.56]	2 [0.15]	3 [0.96]	7 [0.90]	2 [0.50]	2 [0.22]	2 [0.06]	**93386 (137.1 min)**	
		Final Solution	**3 [0.64]**	**2 [0.56]**	**2 [0.15]**	**3 [0.96]**	**7 [0.90]**	**2 [0.50]**	**2 [0.22]**	**1 [0.11]**		
Chatham-K. County (Location #14)	20.4, 27.2, 102 21.5, 28.6, 107.4 21.9, 29.2, 109.6	*First Stable State*	4 [0.75]	3 [0.57]	3 [0.16]	5 [0.92]	10 [0.94]	3 [0.53]	3 [0.23]	3 [0.06]	**144554 (122.9 min)**	
		Final Solution	**4 [0.75]**	**3 [0.57]**	**1 [0.47]**	**5 [0.92]**	**10 [0.95]**	**3 [0.53]**	**2 [0.34]**	**1 [0.19]**		
Essex County (Location #15)	35, 46.7, 175.1 36.9, 49.2, 184.3 37.6, 50.2, 188.1	*First Stable State*	2 [0.87]	2 [0.50]	2 [0.14]	3 [0.87]	7 [0.88]	2 [0.45]	2 [0.20]	2 [0.05]	**84722 (132.4 min)**	
		Final Solution	**2 [0.87]**	**2 [0.50]**	**2 [0.14]**	**3 [0.87]**	**7 [0.88]**	**2 [0.45]**	**2 [0.20]**	**1 [0.11]**		

Table 5.2 Simulation results if only existing facilities are open

Facilty Location	*Interrarrival Time (min) NP1, NP2, NP3 OP1, OP2, OP3 FP1, FP2, FP3*	*Improvement after stable state*	**Necessary Recources**								*Number of Patients (Average Flow Time for Operation Patients)*	*Fixed Cost Access Cost Handling Cost CPU time*
			Colonoscopy Doctor(s) [util.]	*Gastroscopy Doctor(s) [util.]*	*Flexible-S. Doctor(s) [util.]*	*Nurses [util.]*	*PR rooms [util.]*	*Procedure Room(s) type 1 [util.]*	*Procedure Room(s) type 2 [util.]*	*Procedure Room(s) type 3 [util.]*		
Oxford County (Location #18)	3.9, 5.2, 194 4.1, 5.4, 204.2 4.2, 5.6, 208.3	*First Stable State*	26 [0.59]	12 [0.75]	12 [0.20]	37 [0.62]	79 [0.57]	13 [0.62]	12 [0.29]	12 [0.08]	**761191 (133.6 min)**	**6,792,882 60,184,680 14,627,000 5770 sec**
		Final Solution	**25 [0.61]**	**12 [0.75]**	**4 [0.60]**	**37 [0.62]**	**65 [0.70]**	**12 [0.66]**	**11 [0.31]**	**2 [0.46]**		

Table 5.3 Simulation results if only one location is open (theoretical case)

5.1.1 Utilization

When the system reaches a stable state (in terms of congestion), where the average waiting times for acceptance to the clinic is under two weeks, we observe that the average flow time is around 130 minutes. Because of the vast number of resource allocations in their case, it can be concluded that the bottleneck resources are nurses and PR rooms. Considering that the nurses are utilized for all three types of endoscopy procedures and PR rooms are visited twice by every operation patient, the high resource requirement for nurses and PR rooms is understandable.

The inter-arrival time of type 3 patients (flexible-sigmoidoscopy) is high due to less demand compared to other endoscopy procedures. Thus, two type 3 operation rooms are enough, even if we only open a single facility for the whole Western Ontario and assign all the demand to it. That is, two type 3 operation rooms are sufficient for keeping the waiting times under the two week threshold as shown in Table 5.3.

5.1.2 Costs

Initially, costs are divided into three categories: Resource Costs, Fixed Costs, and Unit Access Cost. Resource costs are related to the simulation-based optimized capacity variables, and fixed costs are related to open facilities. Resources include PR and procedure rooms, which are indeed associated with the fixed cost. When the necessary resources are found, the cost of opening PR rooms and procedure rooms are added to the fixed costs and the cost of doctors and nurses are held in a new category called "Handling Cost".

Unit access cost is added to the objective function to incorporate the distances between open facilities and demand locations into the optimization of location-allocation decisions. It is clear that, if the unit access cost is too low the optimal location-allocation decisions will require opening only a single facility. Similarly, too high of a unit access cost would lead to opening one facility in every location. As described in section 2.2.3 we used \$0.45/km for the unit access cost in the base case. To test the proposed methodologies, we have examined various unit access cost scenarios used and results are presented in Section 5.2.1.

Facilty Locations	*Interrarrival Time (min)* *NP1, NP2, NP3* *OP1, OP2, OP3* *FP1, FP2, FP3*	*Improvement after stable state*	**Necessary Recources**								*Number of Patients (Average Flow Time for Operation Patients)*	*Fixed Cost* *Access Cost* *Handling Cost* *CPU time*
			Colonoscopy Doctor(s) [util.]	*Gastroscopy Doctor(s) [util.]*	*Flexible-S. Doctor(s) [util.]*	*Nurses [util.]*	*PR rooms [util.]*	*Procedure Room(s) type 1 [util.]*	*Procedure Room(s) type 2 [util.]*	*Procedure Room(s) type 3 [util.]*		
Oxford County (Location #18)	128.8, 171.7, 644 135.6, 180.8, 677.9 138.3, 184.5, 691.7	*First Stable State*	1 [0.47]	1 [0.28]	1 [0.08]	2 [0.36]	4 [0.36]	1 [0.25]	1 [0.11]	1 [0.03]	**22926 (120.3 min)**	
		Final Solution	**1 [0.47]**	**1 [0.28]**	**1 [0.08]**	**2 [0.36]**	**4 [0.36]**	**1 [0.25]**	**1 [0.11]**	**1 [0.03]**		
Brant County (Location #9)	100.1, 133.5, 500.5 105.4, 140.5, 526.8 107.5, 143.4, 537.6	*First Stable State*	1 [0.60]	1 [0.35]	1 [0.09]	2 [0.46]	4 [0.50]	1 [0.32]	1 [0.14]	1 [0.04]	**29367 (125.3 min)**	
		Final Solution	**1 [0.60]**	**1 [0.35]**	**1 [0.09]**	**2 [0.46]**	**4 [0.50]**	**1 [0.32]**	**1 [0.14]**	**1 [0.04]**		
Waterloo County (Location #7)	26.9, 35.8, 134.2 28.3, 37.7, 141.3 28.8, 38.5, 144.2	*First Stable State*	3 [0.77]	2 [0.66]	2 [0.18]	4 [0.87]	8 [0.94]	2 [0.61]	2 [0.26]	2 [0.07]	**110279 (125.6 min)**	
		Final Solution	**3 [0.76]**	**2 [0.66]**	**1 [0.36]**	**4 [0.87]**	**8 [0.94]**	**2 [0.61]**	**2 [0.29]**	**1 [0.14]**		
Hamilton County (Location #8)	26.2, 34.9, 130.9 27.6, 36.8, 137.8 28.1, 37.5, 140.6	*First Stable State*	3 [0.77]	2 [0.67]	2 [0.18]	4 [0.87]	8 [0.94]	2 [0.60]	2 [0.26]	2 [0.07]	**113250 (124.9 min)**	
		Final Solution	**3 [0.77]**	**2 [0.67]**	**2 [0.18]**	**4 [0.86]**	**8 [0.94]**	**2 [0.60]**	**2 [0.26]**	**1 [0.13]**		
Perth County (Location #6)	181.3, 241.7, 906.4 190.8, 254.4, 954.1 194.7, 259.6, 973.6	*First Stable State*	1 [0.33]	1 [0.19]	1 [0.05]	2 [0.25]	4 [0.24]	1 [0.18]	1 [0.07]	1 [0.02]	**16143 (116.6 min)**	
		Final Solution	**1 [0.33]**	**1 [0.19]**	**1 [0.05]**	**2 [0.25]**	**4 [0.24]**	**1 [0.18]**	**1 [0.07]**	**1 [0.02]**		
Middlesex County (Location #17)	31, 41.3, 155 32.6, 43.5, 163.2 33.3, 44.4, 166.5	*First Stable State*	3 [0.66]	2 [0.57]	2 [0.15]	4 [0.75]	7 [0.84]	2 [0.05]	2 [0.23]	2 [0.06]	**94912 (118.2 min)**	
		Final Solution	**3 [0.66]**	**2 [0.57]**	**1 [0.31]**	**4 [0.75]**	**6 [0.98]**	**2 [0.52]**	**1 [0.46]**	**1 [0.12]**		
Norfolk County (Location #12)	215.5, 287.4, 1077.7 226.9, 302.5, 1134.4 231.5, 308.7, 1157.5	*First Stable State*	1 [0.28]	1 [0.17]	1 [0.04]	2 [0.21]	4 [0.20]	1 [0.15]	1 [0.7]	1 [0.02]	**13702 (115.7 min)**	
		Final Solution	**1 [0.28]**	**1 [0.17]**	**1 [0.04]**	**2 [0.21]**	**4 [0.20]**	**1 [0.15]**	**1 [0.7]**	**1 [0.02]**		
Wellington County (Location #4)	65.4, 87.1, 326.8 68.8, 91.7, 344 70.2, 93.6, 351	*First Stable State*	2 [0.47]	1 [0.56]	1 [0.14]	2 [0.71]	5 [0.71]	1 [0.50]	1 [0.21]	1 [0.06]	**45189 (129.5 min)**	
		Final Solution	**2 [0.47]**	**1 [0.56]**	**1 [0.14]**	**2 [0.71]**	**4 [0.77]**	**1 [0.50]**	**1 [0.21]**	**1 [0.06]**		
Haldimand County (Location #10)	303.4, 404.6, 1517.1 319.4, 425.9, 1597 325.9, 434.6, 1629.6	*First Stable State*	1 [0.20]	1 [0.12]	1 [0.03]	2 [0.15]	4 [0.14]	1 [0.11]	1 [0.04]	1 [0.01]	**9696 (114.4 min)**	**29,363,813** **0** **23,023,000** **5544.8 sec**
		Final Solution	**1 [0.20]**	**1 [0.12]**	**1 [0.03]**	**2 [0.15]**	**4 [0.14]**	**1 [0.11]**	**1 [0.04]**	**1 [0.01]**		
Elgin County (Location #13)	155.7, 207.6, 778.4 163.9, 218.5, 819.4 167.2, 223, 836.1	*First Stable State*	1 [0.40]	1 [0.24]	1 [0.06]	2 [0.30]	4 [0.29]	1 [0.22]	1 [0.09]	1 [0.02]	**19109 (118.2 min)**	
		Final Solution	**1 [0.40]**	**1 [0.24]**	**1 [0.06]**	**2 [0.30]**	**4 [0.29]**	**1 [0.22]**	**1 [0.09]**	**1 [0.02]**		
Huron County (Location #5)	230.4, 307.2, 1152 242.5, 323.4, 1212.6 247.5, 330, 1237.4	*First Stable State*	1 [0.27]	1 [0.15]	1 [0.04]	2 [0.20]	4 [0.19]	1 [0.14]	1 [0.06]	1 [0.02]	**12806 (115.5 min)**	
		Final Solution	**1 [0.27]**	**1 [0.15]**	**1 [0.04]**	**2 [0.20]**	**4 [0.19]**	**1 [0.14]**	**1 [0.06]**	**1 [0.02]**		
Niagara County (Location #11)	31.6, 45.1, 157.8 33.2, 44.3, 166.1 33.9, 45.2, 169.5	*First Stable State*	3 [0.65]	2 [0.56]	2 [0.15]	4 [0.73]	7 [0.83]	2 [0.51]	2 [0.22]	2 [0.06]	**93370 (118 min)**	
		Final Solution	**3 [0.65]**	**2 [0.56]**	**1 [0.30]**	**4 [0.73]**	**6 [0.97]**	**2 [0.51]**	**1 [0.44]**	**1 [0.12]**		
Dufferin County (Location #3)	239.4, 319.2, 1197 252, 336, 1260 257.1, 342.8, 1285.6	*First Stable State*	1 [0.26]	1 [0.14]	1 [0.04]	2 [0.19]	4 [0.18]	1 [0.14]	1 [0.05]	1 [0.01]	**12312 (115.5 min)**	
		Final Solution	**1 [0.26]**	**1 [0.14]**	**1 [0.04]**	**2 [0.19]**	**4 [0.18]**	**1 [0.14]**	**1 [0.05]**	**1 [0.01]**		
Lambition County (Location #16)	109.3, 145.7, 546.3 115, 153.4, 575.1 117.4, 156.5, 586.8	*First Stable State*	1 [0.56]	1 [0.33]	1 [0.09]	2 [0.43]	4 [0.44]	1 [0.31]	1 [0.13]	1 [0.03]	**27207 (123.9 min)**	
		Final Solution	**1 [0.56]**	**1 [0.33]**	**1 [0.09]**	**2 [0.43]**	**4 [0.44]**	**1 [0.31]**	**1 [0.13]**	**1 [0.03]**		
Bruce County (Location #1)	206, 274.7, 1030 216.8, 289.1, 1084.2 221.3, 295, 1106.3	*First Stable State*	1 [0.30]	1 [0.17]	1 [0.05]	2 [0.23]	4 [0.22]	1 [0.16]	1 [0.07]	1 [0.02]	**14329 (115.9 min)**	
		Final Solution	**1 [0.30]**	**1 [0.17]**	**1 [0.05]**	**2 [0.23]**	**4 [0.22]**	**1 [0.16]**	**1 [0.07]**	**1 [0.02]**		
Chatham-Kent County (Location #14)	131.4, 175.2, 656.8 138.3, 184.4, 691.4 141.1, 188.1, 705.5	*First Stable State*	1 [0.45]	1 [0.30]	1 [0.07]	2 [0.36]	4 [0.36]	1 [0.25]	1 [0.11]	1 [0.03]	**22722 (119.6 min)**	
		Final Solution	**1 [0.45]**	**1 [0.30]**	**1 [0.07]**	**2 [0.36]**	**4 [0.36]**	**1 [0.25]**	**1 [0.11]**	**1 [0.03]**		
Grey County (Location #2)	147.1, 196.1, 735.5 154.8, 206.5, 774.2 158, 210.7, 790	*First Stable State*	1 [0.41]	1 [0.25]	1 [0.06]	2 [0.31]	4 [0.31]	1 [0.21]	1 [0.10]	1 [0.02]	**20103 (119 min)**	
		Final Solution	**1 [0.41]**	**1 [0.25]**	**1 [0.06]**	**2 [0.31]**	**4 [0.31]**	**1 [0.21]**	**1 [0.10]**	**1 [0.02]**		
Essex County (Location #15)	35, 46.7, 175.1 36.9, 49.2, 184.3 37.6, 50.2, 188.1	*First Stable State*	2 [0.88]	2 [0.50]	2 [0.13]	3 [0.86]	7 [0.88]	2 [0.46]	2 [0.19]	2 [0.05]	**84792 (187.5 min)**	
		Final Solution	**2 [0.88]**	**2 [0.50]**	**2 [0.13]**	**3 [0.86]**	**7 [0.88]**	**2 [0.46]**	**2 [0.19]**	**2 [0.05]**		

Table 5.4 Simulation results if all facilities are open

It can be seen that fixed and handling costs of opening facilities in all demand locations (Table 5.4) are at least twice those for opening a single facility (Table 5.3). The reason is that opening a facility in every location requires at least one of each resource in some facilities despite very low arrival rates. Opening a facility in every location is associated with a higher number of resources with lower utilization rates per resource. We can conclude that, if unit access cost is not a concern, it is better to open a single facility to reach high resource utilization and keep costs to a minimum. However, the unit access cost, which specifies the contribution of total travel cost to the total cost, shifts the optimality from a centralized towards a distributed one. The opening of five facilities has less total cost than opening a single facility and opening all facilities, as the single facility increases access cost and a facility for every location increases fixed cost significantly.

5.2 Numerical Experiments and Optimization Result

As mentioned before, three heuristics were used to solve the problem: greedy adding (GA), simulated annealing (SA), and a combination of GA and SA. As we have five clinics already open in particular locations, the algorithm starts with considering these open facilities and calculate the associated costs.

At the top left corner of Table 5.5-5.7, *k*$\in \{5,6,7,..18\}$ represents the number of open facilities. We solve the location-allocation model for each *k* because i) we want to address how the solution quality changes over *k*, ii) the decision makers may have additional constraints on the minimum and maximum number of open facilities. For each *k* value, SA search solutions for exactly *k* open facilities, and we force GA to open *k* facilities even if it increases the cost.

To evaluate the performance of the heuristics, we investigated three specific cost scenarios: dominant access cost (Table 5.5), dominant handling cost (Table 5.6), and dominant fixed cost (Table 5.7). We define a cost as dominant if that cost constitutes 70-80% of the total costs of the initial solution (only 5 existing locations are open). Column 2, 3 and 4 in these three tables show the percentages of fixed cost (FC), access cost (AC), and handling cost (HC) in the total cost obtained by GA, respectively. In each table, percentage of access cost decreases and percentage of fixed cost increases as *k* increases.

In the next three columns the heuristics are ordered according to the objective function values they achived. The remaining columns provide the best objective function value found by each proposed algorithm.

In addition, we evaluated the performance of these heuristics for varying compliance rates $\alpha \in \{1, 0.8, 0.6\}$ (proportion of the 50-74 year-old patients who follow the guidelines and visit the clinics for screening every 10 years).

5.2.1 Performance of the Proposed Methods

It is obvious that if the number of open facilities is five or eighteen there is no need to run the heuristics as the locations to open are already known, e.g., keeping only the five existing clinics and having an open facility in all facility locations, respectively. For the other thirteen cases ($5<k<18$), the three proposed heuristics are run to find the Location–allocation decisions.

Computational Time

As the number of open facilities increases, the required computational time for GA heuristic increases. This is because the procedure is supposed to check k=6 to k= i-1 before finding a solution for k=i.

On the other hand, computational time of SA and GA+SA heuristics decreases gradually after k passes a particular threshold because i) more locations means lower demand for each region and fewer resource combinations to search among; ii) the possible combinations of choosing k out of 18 decreases after a certain point. This trend can be observed in all of the Tables 5.5, 5.6, and 5.7. In average, as the number of open facilities (k) increases, the whole endoscopy clinic network reaches a state that even the base resource level is enough to receive all demand with the desired waiting times and there is no need to examine the addition of resources. GA is faster than SA and GA+SA while SA and GA+SA have similar computational times.

As expected, the compliance rate (α) has a significant effect on the computation time because decreasing α also decreases the demand which limits the search base for the resource allocation.

Best Performance

Table 5.5 shows that if the access cost is the dominant cost among the others, GA heuristic provides the best solution for all α values, while GA+SA also reaches the same solutions as it starts from solutions found by GA. Therefore, SA and GA + SA do not contribute in improving the solution quality compared to GA.

However, in the dominant handling cost case, GA performs better only in small capacity levels; whereas SA and GA+SA perform better in high capacity cases. In most *k* values where GA fails to obtain the best solution, GA + SA performs the best. However, there are also several cases where SA has the best performance. This especially occurs when GA gets stuck at a local minimum, far from a global minimum (understood from the performance gap between GA and the best heuristic). Therefore, SA starting from this local minimum, doesn't improve the solution any further.

Finally, in the dominant fixed cost case, GA fails to find a good solution in most capacity instances. GA+SA tend to find the best or better results, while the performance of SA fluctuates.

In average, GA+SA is associated with the better performance; however, in particular cases using only GA (e.g., the case of dominant access cost) can save significant amounts of time by minimally sacrificing the solution quality. In addition, in a few cases (e.g., α=0.6 and dominant handling cost) using SA leads to good solutions.

Comparison between *k*-levels

As it has been mentioned before, each number of open facilities (*k*) represents the minimum cost when exactly k facilities are open. We can easily compare the results to see how many facilities should be opened. When access cost is dominant, seventeen facilities are open. This number is six facilities when either fixed cost or handling cost is dominant. Note that the solutions for the cases of dominant fixed and handling costs are not necessarily the same.

k	Costs (%)			CPU (sec)			Best Solution (Order)			Best Solution (Obj. Value)		
	FC	AC	HC	GA	SA	GA+SA	GA	SA	GA+SA	GA	SA	GA+SA
α = 1												
5	6.8	84.2	9.0	1157.1	1157.1	1157.1	-	-	-	158,150,000	158,150,000	158,150,000
6	11.3	75.0	13.8	3663.2	23284.4	24713.5	*	*	*	107,290,000	107,290,000	107,290,000
7	14.9	68.3	16.8	5097.3	32295.4	35422.8	1	3	1	90,333,000	99,470,000	90,333,000
8	18.0	63.2	18.8	6269.1	29802.7	31045.6	1	3	2	82,769,000	84,790,000	82,990,000
9	21.2	57.5	21.2	7152.0	27817.1	28583.5	1	3	1	75,642,000	78,780,000	75,642,000
10	25.9	49.5	24.9	8097.7	26818.7	27394.0	1	3	1	68,554,000	75,220,000	68,554,000
11	29.4	43.6	27.0	9527.7	25210.1	26827.1	1	3	1	65,106,000	67,960,000	65,106,000
12	33.1	36.7	30.2	10335.4	25856.6	23733.4	1	3	1	61,557,000	65,176,000	61,557,000
13	37.0	30.4	32.5	11828.2	20165.5	22001.8	1	3	1	59,328,000	64,371,000	59,328,000
14	41.1	24.5	34.4	12554.3	19240.1	21173.4	1	3	1	56,662,000	58,018,000	56,662,000
15	45.6	17.4	37.0	13426.9	17948.9	20895.4	1	1	1	54,236,000	54,236,000	54,236,000
16	49.6	10.5	39.9	13745.2	17673.3	19291.3	1	3	1	52,616,000	53,298,000	52,616,000
17	53.5	4.1	42.4	13948.7	17431.5	18445.4	*	*	*	51,421,000	51,421,000	51,421,000
18	55.9	0.0	44.1	454.7	454.7	454.7	-	-	-	52,388,533	52,388,533	52,388,533
k	Costs (%)			CPU (sec)			Best Solution (Order)			Best Solution (Obj. Value)		
	FC	AC	HC	GA	SA	GA+SA	GA	SA	GA+SA	GA	SA	GA+SA
α = 0.8												
5	7.9	83.1	9.0	1172.0	1172.0	1172.0	-	-	-	127,970,000	127,970,000	127,970,000
6	13.2	73.0	13.8	2279.7	13273.2	13871.4	*	*	*	87,765,000	87,765,000	87,765,000
7	16.9	66.0	17.1	3260.3	20112.2	20179.6	1	3	2	74,685,000	76,850,000	74,680,000
8	20.3	60.2	19.5	4167.6	18139.4	18693.4	2	1	2	69,760,000	69,390,000	69,760,000
9	24.3	54.2	21.6	5008.8	17561.0	17466.7	1	3	1	63,574,000	65,190,000	63,574,000
10	28.8	46.6	24.6	5838.7	17508.1	17168.7	1	3	1	58,271,000	65,540,000	58,271,000
11	32.5	40.5	27.0	6632.3	16908.1	14712.1	1	3	1	55,616,000	56,386,000	55,616,000
12	36.4	34.0	29.6	7086.4	14360.1	15371.3	1	3	1	53,909,000	54,948,000	53,909,000
13	40.3	27.3	32.3	7589.7	14363.3	14715.6	1	3	1	52,314,000	54,090,000	52,314,000
14	43.8	21.6	34.6	8090.6	14931.1	12312.4	1	3	1	51,294,000	55,266,000	51,294,000
15	47.9	15.0	37.1	8640.0	13232.9	11449.2	1	3	1	50,313,000	51,693,000	50,313,000
16	51.6	9.0	39.5	9198.8	13135.0	11549.3	1	3	1	49,708,000	49,758,000	49,708,000
17	55.2	3.5	41.3	9735.6	5677.7	7477.0	*	*	*	49,182,000	49,182,000	49,182,000
18	57.4	0.0	42.6	520.7	520.7	520.7	-	-	-	49,968,146	49,968,146	49,968,146
k	Costs (%)			CPU (sec)			Best Solution (Order)			Best Solution (Obj. Value)		
	FC	AC	HC	GA	SA	GA+SA	GA	SA	GA+SA	GA	SA	GA+SA
α = 0.6												
5	9.1	81.2	9.7	636.8	636.8	636.8	-	-	-	98,323,000	98,323,000	98,323,000
6	15.4	70.1	14.5	1250.0	8536.1	8441.2	*	*	*	68,504,000	68,504,000	68,504,000
7	19.8	62.4	17.7	1760.4	11270.7	12560.4	1	3	1	59,660,000	63,259,000	59,660,000
8	23.7	56.5	19.8	2272.3	10221.7	10524.4	2	1	1	55,683,000	56,472,000	55,683,000
9	27.9	49.5	22.5	2750.2	9246.1	9334.6	1	3	1	52,132,000	53,056,000	52,132,000
10	32.9	41.7	25.4	3215.4	9107.5	9085.7	1	3	1	48,857,000	50,049,000	48,857,000
11	36.5	35.4	28.1	3624.5	9063.3	10007.1	1	3	1	47,692,000	51,038,000	47,692,000
12	40.3	29.2	30.5	4000.1	8892.0	8825.2	1	3	1	47,038,000	47,723,000	47,038,000
13	44.0	23.0	33.0	4386.9	8670.4	8712.0	1	3	1	46,513,000	50,600,000	46,513,000
14	47.6	18.2	34.2	4779.8	8042.3	7922.5	1	3	1	45,761,000	46,587,000	45,761,000
15	51.4	12.6	36.0	5155.3	7815.5	7672.6	1	3	1	45,157,000	46,131,000	45,157,000
16	54.6	7.4	38.0	5535.2	7426.3	7279.4	1	3	1	45,329,000	46,280,000	45,329,000
17	57.4	2.8	39.8	5910.3	4578.3	4686.3	*	*	*	45,778,000	45,778,000	45,778,000
18	59.2	0.0	40.8	369.7	369.7	369.7	-	-	-	46,992,541	46,992,541	46,992,541

Table 5.5 Statistics for dominant unit access cost

k	Costs (%)			CPU (sec)			Best Solution (Order)			Best Solution (Obj. Value)		
	FC	AC	HC	GA	SA	GA+SA	GA	SA	GA+SA	GA	SA	GA+SA
α = 1												
5	5.5	21.7	72.7	2148.8	2148.8	2148.8	-	-	-	195,740,000	195,740,000	195,740,000
6	6.7	14.0	79.3	4215.1	24160.7	25351.2	*	*	*	184,700,000	184,700,000	184,700,000
7	7.3	10.6	82.0	5113.6	32646.4	32180.5	2	3	1	185,380,000	187,690,000	182,010,000
8	7.9	9.0	83.1	6361.4	31466.1	29006.7	2	3	1	187,270,000	193,010,000	186,270,000
9	8.5	7.3	84.2	7058.9	29213.2	27676.7	2	3	1	190,260,000	196,840,000	189,290,000
10	9.1	5.5	85.4	8145.5	24365.6	26588.2	1	3	1	190,390,000	203,300,000	190,390,000
11	9.3	4.4	86.3	9644.1	28016.6	26924.0	2	1	2	199,100,000	193,220,000	199,100,000
12	9.6	3.5	87.0	10742.5	25229.6	23426.2	3	1	2	212,220,000	201,200,000	207,390,000
13	9.8	2.6	87.5	11488.0	20665.3	20837.7	3	2	1	219,430,000	213,710,000	210,120,000
14	10.5	2.0	87.5	12971.3	20533.2	21141.7	3	2	1	222,300,000	220,760,000	217,410,000
15	10.8	1.3	87.9	13545.2	18562.4	20693.3	3	1	2	230,740,000	226,470,000	228,950,000
16	11.1	0.8	88.2	13698.7	17844.9	18878.3	3	1	2	236,630,000	235,280,000	236,160,000
17	11.2	0.3	88.6	14957.4	5612.4	1945.8	*	*	*	245,000,000	245,000,000	245,000,000
18	11.2	0.0	88.8	878.2	878.2	878.2	-	-	-	258,264,914	258,264,914	258,264,914
k	Costs (%)			CPU (sec)			Best Solution (Order)			Best Solution (Obj. Value)		
	FC	AC	HC	GA	SA	GA+SA	GA	SA	GA+SA	GA	SA	GA+SA
α = 0.8												
5	6.4	21.7	71.9	1246.7	1246.7	1246.7	-	-	-	156,760,000	156,760,000	156,760,000
6	7.7	13.4	79.0	2413.5	15159.8	14100.6	*	*	*	153,400,000	153,400,000	153,400,000
7	8.2	10.1	81.7	3414.9	30646.3	29826.5	3	2	1	155,840,000	152,940,000	152,080,000
8	8.6	8.2	83.1	4377.0	28701.0	28188.9	3	1	2	163,390,000	158,950,000	160,030,000
9	9.4	6.7	83.9	5233.0	25106.5	25847.3	2	3	1	163,460,000	165,910,000	159,780,000
10	9.9	5.2	85.0	6084.4	27652.4	27288.2	1	3	1	168,640,000	169,620,000	168,640,000
11	10.3	4.1	85.6	6891.6	24628.5	24027.3	2	3	1	175,250,000	180,990,000	175,100,000
12	10.6	3.2	86.3	7570.8	20722.8	20780.2	2	3	1	185,150,000	189,410,000	184,700,000
13	10.8	2.3	86.8	8239.7	20736.0	20938.9	2	3	1	194,430,000	194,620,000	194,110,000
14	11.0	1.7	87.2	8837.0	19272.7	19983.0	3	2	1	203,300,000	202,440,000	202,250,000
15	11.4	1.1	87.5	9461.5	18189.4	18533.8	3	1	2	212,840,000	210,830,000	211,370,000
16	11.5	0.6	87.8	10082.1	4390.2	3168.0	2	3	1	222,990,000	220,800,000	220,320,000
17	11.8	0.2	87.9	10698.7	878.2	878.2	*	*	*	228,290,000	228,290,000	228,290,000
18	11.8	0.0	88.2	608.2	608.2	608.2	-	-	-	241,202,108	241,202,108	241,202,108
k	Costs (%)			CPU (sec)			Best Solution (Order)			Best Solution (Obj. Value)		
	FC	AC	HC	GA	SA	GA+SA	GA	SA	GA+SA	GA	SA	GA+SA
α = 0.6												
5	7.0	19.3	73.7	630.4	630.4	630.4	-	-	-	132,160,000	132,160,000	132,160,000
6	8.3	12.0	79.6	1245.6	30509.7	29963.1	*	*	*	127,500,000	127,500,000	127,500,000
7	9.0	9.2	81.8	1784.3	28615.7	28274.2	2	1	2	128,760,000	128,620,000	128,760,000
8	9.8	7.5	82.6	2292.8	25229.9	25723.9	1	1	1	132,060,000	132,060,000	132,060,000
9	10.3	5.9	83.8	2778.8	27591.7	27348.9	1	1	1	140,290,000	140,290,000	140,290,000
10	10.9	4.4	84.7	3243.7	24528.3	24127.5	2	3	1	146,680,000	148,440,000	145,930,000
11	11.0	3.5	85.5	3652.2	20732.3	20770.7	3	1	2	156,630,000	153,170,000	155,540,000
12	11.3	2.6	86.1	4049.4	20769.8	20905.1	3	1	2	166,870,000	161,170,000	162,030,000
13	11.5	1.9	86.5	4451.0	19391.1	19864.6	3	1	2	177,300,000	167,730,000	171,490,000
14	12.0	1.5	86.5	4857.9	18246.8	18476.4	1	1	1	181,060,000	181,290,000	181,060,000
15	12.4	1.0	86.7	5251.4	4186.5	3371.7	1	3	1	187,800,000	188,300,000	187,800,000
16*	12.5	0.5	86.9	5669.7	878.2	878.2	1	1	1	198,350,000	198,350,000	198,350,000
17	12.6	0.2	87.2	6052.6	608.2	608.2	*	*	*	208,900,000	208,900,000	208,900,000
18	12.7	0.0	87.3	381.8	381.8	381.8	-	-	-	219,702,541	219,702,541	219,702,541

Table 5.6 Statistics for dominant handling cost. (*) All three heuristics found same solution

k	Costs (%)			CPU (sec)			Best Solution (Order)			Best Solution (Obj. Value)		
	FC	AC	HC	GA	SA	GA+SA	GA	SA	GA+SA	GA	SA	GA+SA
α = 1												
5	65.7	25.6	8.5	1848.2	1848.2	1848.2	-	-	-	166,200,000	166,200,000	166,200,000
6	75.3	15.7	8.9	3593.8	1911.2	1852.0	*	*	*	162,740,000	162,740,000	162,740,000
7	79.6	11.6	8.9	5074.3	31931.0	28223.3	3	2	1	173,580,000	171,500,000	171,200,000
8	81.9	9.4	8.7	6397.8	29159.3	24156.5	3	1	2	182,170,000	180,590,000	180,820,000
9	84.1	7.3	8.5	7715.6	27142.7	23703.7	1	3	1	192,570,000	197,980,000	192,570,000
10	86.4	5.3	8.2	8843.6	27182.3	21338.5	3	1	2	208,410,000	203,590,000	204,910,000
11	87.5	4.2	8.2	10052.2	25468.6	20578.8	2	3	1	216,040,000	218,430,000	214,700,000
12	88.6	3.2	8.2	11224.7	21931.4	26986.0	1	3	1	228,950,000	229,360,000	228,950,000
13	89.7	2.4	7.9	12303.8	23165.6	23491.8	2	1	2	245,550,000	242,440,000	245,550,000
14	90.7	1.7	7.6	13214.7	22260.7	22859.7	2	3	1	256,230,000	256,750,000	255,730,000
15	91.4	1.1	7.5	14019.5	19984.5	22007.3	3	2	1	270,840,000	270,370,000	268,680,000
16	91.9	0.6	7.4	14909.2	20734.6	20857.9	3	1	2	286,420,000	285,020,000	285,570,000
17	92.5	0.2	7.2	15666.6	1883.6	1755.6	*	*	*	298,360,000	298,360,000	298,360,000
18	92.9	0.0	7.1	637.5	637.5	637.5	-	-	-	315,678,950	315,678,950	315,678,950
k	Costs (%)			CPU (sec)			Best Solution (Order)			Best Solution (Obj. Value)		
	FC	AC	HC	GA	SA	GA+SA	GA	SA	GA+SA	GA	SA	GA+SA
α = 0.8												
5	69.2	23.2	7.7	1192.2	1192.2	1192.2	-	-	-	146,890,000	146,890,000	146,890,000
6	78.1	13.8	8.1	2305.6	16167.1	15370.6	*	*	*	145,740,000	145,740,000	145,740,000
7	81.5	10.3	8.2	3332.1	20502.9	22236.8	1	1	1	153,260,000	153,260,000	153,260,000
8	84.0	8.0	8.1	4253.0	20037	14308.4	3	2	1	169,620,000	169,280,000	166,020,000
9	86.2	6.2	7.7	5129.2	18769.8	17195.4	1	3	1	178,690,000	178,950,000	178,690,000
10	87.9	4.6	7.5	6003.5	18219.5	17938.9	2	3	1	190,490,000	193,810,000	190,280,000
11	89.0	3.6	7.4	6779.0	17125.9	17429.9	1	3	1	202,170,000	204,580,000	202,170,000
12	90.0	2.7	7.4	7468.3	16493.5	15701.2	2	3	1	216,720,000	218,570,000	216,650,000
13	91.0	2.0	7.3	8150.2	14026.8	14491.5	3	2	1	232,790,000	232,090,000	231,630,000
14	91.3	1.4	7.2	8791.9	13482.1	10802.8	3	1	2	246,010,000	245,260,000	245,810,000
15	91.9	0.9	7.2	9373.5	13684.7	9772.1	1	1	1	259,690,000	259,690,000	259,690,000
16	92.3	0.5	7.1	9967.0	13066.5	12339.4	3	1	2	276,000,000	275,380,000	275,730,000
17	92.8	0.2	7.0	10538.3	8947.6	8482.4	*	*	*	290,080,000	290,080,000	290,080,000
18	93.1	0.0	6.9	572.6	572.6	572.6	-	-	-	306,192,080	306,192,080	306,192,080
k	Costs (%)			CPU (sec)			Best Solution (Order)			Best Solution (Obj. Value)		
	FC	AC	HC	GA	SA	GA+SA	GA	SA	GA+SA	GA	SA	GA+SA
α = 0.6												
5	72.4	20.1	7.5	622.3	622.3	622.3	-	-	-	127,200,000	127,200,000	127,200,000
6	80.5	11.8	7.8	1214.8	9321.2	9411.3	*	*	*	130,750,000	130,750,000	130,750,000
7	84.1	8.4	7.5	1736.5	12041.2	11879.4	1	3	1	140,330,000	141,610,000	140,330,000
8	86.0	6.7	7.3	2304.6	10835.9	10951.0	2	1	2	149,970,000	149,790,000	149,970,000
9	87.9	5.0	7.1	2800.6	10137.4	10794.4	2	1	2	165,340,000	164,900,000	165,340,000
10	89.4	3.6	6.9	3263.4	9964.7	10501.3	3	2	1	179,520,000	178,780,000	178,620,000
11	90.2	2.8	7.0	3668.7	9364.4	9697.9	2	1	2	192,890,000	192,820,000	192,890,000
12	91.0	2.1	6.9	4052.0	9747.6	8845.0	2	3	1	208,160,000	210,360,000	206,940,000
13	91.5	1.5	6.9	4437.8	9223.6	8368.8	3	1	2	222,060,000	221,000,000	221,480,000
14	92.3	1.1	6.6	4825.9	8548.4	8118.6	3	2	1	236,860,000	234,900,000	234,680,000
15	92.8	0.7	6.5	5143.6	8280.7	7847.7	1	3	1	249,560,000	250,930,000	249,560,000
16	93.1	0.4	6.5	5524.9	8192.6	7911.3	3	2	1	266,110,000	265,730,000	265,430,000
17	93.4	0.1	6.5	5907.2	4994.1	4916.5	*	*	*	282,120,000	282,120,000	282,120,000
18	93.6	0.0	6.4	403.6	403.6	403.6	-	-	-	298,240,600	298,240,600	298,240,600

Table 5.7 Statistics for dominant fixed cost

5.3 Optimization Result

If access cost is the dominant cost, all three heuristics shows that the optimum decision is to open all facilities except the facility at Haldimand County (See table 5.5). The required resources and the utilization rate in each facility are given in Table 5.8. However, if the arrival rate drops to 60% of for eligible patients, the cost effective method (found both by GA and GA+SA) is to open all facilities in all locations except Haldimand, Dufferin, and Norfolk Counties.

Facilty Locations	*Interrarrival Time (min)* *NP1, NP2, NP3* *OP1, OP2, OP3* *FP1, FP2, FP3*	**Necessary Recources**								*Number of Patients* *(Average Flow Time Operation Patients)*	*Fixed Cost* *Access Cost* *Handling Cost* *CPU time*
		Colonoscopy Doctor(s) [util.]	*Gastroscopy Doctor(s) [util.]*	*Flexible-S. Doctor(s) [util.]*	*Nurses [util.]*	*PR rooms [util.]*	*Procedure Room(s) type 1 [util.]*	*Procedure Room(s) type 2 [util.]*	*Procedure Room(s) type 3 [util.]*		
Bruce County (Location #1)	206, 274.7, 1030 216.8, 289.1, 1084 221.3, 295, 1106	**1 [0.30]**	**1 [0.05]**	**1 [0.05]**	**2 [0.23]**	**4 [0.22]**	**1 [0.15]**	**1 [0.07]**	**1 [0.02]**	**14396 (115.8 min)**	
Grey County (Location #2)	147.1, 196.1, 735.5 154.8, 206.5, 774.2 158, 210.7, 790	**1 [0.41]**	**1 [0.24]**	**1 [0.07]**	**2 [0.31]**	**4 [0.31]**	**1 [0.22]**	**1 [0.10]**	**1 [0.03]**	**20099 (118.9 min)**	
Dufferin County (Location #3)	239.4, 319.2, 1196.9 252, 336, 1259.9 257.1, 342.8, 1285.6	**1 [0.26]**	**1 [0.15]**	**1 [0.04]**	**2 [0.20]**	**4 [0.20]**	**1 [0.14]**	**1 [0.06]**	**1 [0.02]**	**12429 (115.8 min)**	
Wellington County (Location #4)	65.4, 87.1, 326.8 68.8, 91.7, 344 70.2, 96.6, 351	**2 [0.47]**	**1 [0.55]**	**1 [0.14]**	**2 [0.72]**	**4 [0.78]**	**1 [0.50]**	**1 [0.22]**	**1 [0.06]**	**45368 (130.4 min)**	
Huron County (Location #5)	230.4, 307.2, 115 242.5, 323.4, 1212.6 247.5, 330, 1237.4	**1 [0.26]**	**1 [0.16]**	**1 [0.04]**	**2 [0.21]**	**4 [0.20]**	**1 [0.14]**	**1 [0.06]**	**1 [0.02]**	**12986 (115.5 min)**	
Perth County (Location #6)	181.3, 241.7, 806.4 190.8, 254.4, 954.1 194.7, 259.6, 973.6	**1 [0.34]**	**1 [0.20]**	**1 [0.05]**	**2 [0.25]**	**4 [0.25]**	**1 [0.20]**	**1 [0.08]**	**1 [0.02]**	**16292 (117 min)**	
Waterloo County (Location #7)	26.9, 35.8, 134.3 28.3, 37.7, 141.3 28.8, 38.5, 144.2	**3 [0.76]**	**2 [0.66]**	**1 [0.36]**	**4 [0.86]**	**8 [0.94**	**2 [0.60]**	**2 [0.26]**	**1 [0.13]**	**110254 (125.4 min)**	
Hamilton County (Location #8)	26.2, 34.9, 130.9 27.6, 36.8, 137.8 28.1, 37.5, 140.6	**3 [0.77]**	**2 [0.68]**	**1 [0.36]**	**4 [0.87]**	**9 [0.88]**	**2 [0.60]**	**2 [0.27]**	**1 [0.14]**	**113144 (130.5 min)**	
Brant County (Location #9)	75.3, 100.4, 376.3 79.2, 105.6, 396.1 80.8, 107.8, 404.2	**1 [0.82]**	**1 [0.47]**	**1 [0.13]**	**2 [0.62]**	**4 [0.75]**	**1 [0.44]**	**1 [0.18]**	**1 [0.05]**	**39323 (139.7 min)**	**27,753,793 2,145,800 21,773,000 472.9 sec**
Niagara County (Location #11)	31.6, 42.1, 157.8 33.2, 44.3, 166.1 33.9, 45.2, 169.5	**3 [0.65]**	**2 [0.56]**	**1 [0.29]**	**4 [0.74]**	**6 [0.97]**	**2 [0.52]**	**1 [0.45]**	**1 [0.12]**	**93675 (118.2 min)**	
Norfolk County (Location #12)	215.5, 287.4, 1077.7 226.9, 302.5, 1134.4 231.5, 308.7, 1157.5	**1 [0.28]**	**1 [0.16]**	**1 [0.05]**	**2 [0.22]**	**4 [0.21]**	**1 [0.15]**	**1 [0.07]**	**1 [0.02]**	**13657 (116.1 min)**	
Elgin County (Location #13)	155.9, 207.6, 778.4 163.9, 218.5, 819.4 167.2, 223, 836.1	**1 [0.40]**	**1 [0.23]**	**1 [0.06]**	**2 [0.30]**	**4 [0.30]**	**1 [0.21]**	**1 [0.10]**	**1 [0.02]**	**19098 (118.6 min)**	
Chatham-Kent County (Location #14)	131.4, 175.2, 656.8 138.3, 184.4, 691.4 141.1, 188.1, 705.5	**1 [0.48]**	**1 [0.27]**	**1 [0.07]**	**2 [0.36]**	**4 [0.35]**	**1 [0.25]**	**1 [0.11]**	**1 [0.03]**	**22498 (120.7 min)**	
Essex County (Location #15)	35, 46.7, 175.1 36.9, 49.2, 184.3 37.6, 50.2, 188.1	**2 [0.86]**	**2 [0.50]**	**1 [0.27]**	**3 [0.87]**	**7 [0.88]**	**2 [0.46]**	**2 [0.20]**	**1 [0.10]**	**83916 (132.4 min)**	
Lambton County (Location #16)	109.3, 145.9, 546.3 115, 153.5, 575.1 117.4, 156.5, 586.8	**1 [0.56]**	**1 [0.33]**	**1 [0.09]**	**2 [0.43]**	**4 [0.45]**	**1 [0.30]**	**1 [0.13]**	**1 [0.03]**	**26978 (123.8 min)**	
Middlesex County (Location #17)	31, 41.3, 155 32.6, 43.5, 163.2 33.3, 44.4, 166.5	**3 [0.66]**	**2 [0.57]**	**1 [0.30]**	**4 [0.75]**	**6 [0.99]**	**2 [0.53]**	**1 [0.45]**	**1 [0.12]**	**95387 (118.1 min)**	
Oxford County (Location #18)	128.8, 171.7, 644 135.6, 180.8, 677.9 138.3, 184.5, 691.7	**1 [0.47]**	**1 [0.23]**	**1 [0.07]**	**2 [0.37]**	**4 [0.37]**	**1 [0.26]**	**1 [0.11]**	**1 [0.03]**	**22923 (120.1 min)**	

Table 5.8 Open facilities and resource allocation if access cost is dominant

If handling cost is the dominant cost, the minimum cost is found by GA+SA when seven facilities are utilized (See table 5.6). The optimum decision is to open two more facilities at Bruce and Middlesex Counties in addition to five existing facilities. The required resources and the utilization rate in each facility are given in Table 5.8. However if the arrival rate drops to 60% of the eligible patients it is better not to open the facility at Bruce County as it leads to a cost increase.

Facilty Locations	*Interrarrival Time (min)*	**Necessary Recources**								*Number of Patients (Average Flow Time Operation Patients)*	*Fixed Cost Access Cost Handling Cost CPU time*
	NP1, NP2, NP3 OP1, OP2, OP3 FP1, FP2, FP3	*Colonoscopy Doctor(s) [util.]*	*Gastroscopy Doctor(s) [util.]*	*Flexible-S. Doctor(s) [util.]*	*Nurses [util.]*	*PR rooms [util.]*	*Procedure Room(s) type 1 [util.]*	*Procedure Room(s) type 2 [util.]*	*Procedure Room(s) type 3 [util.]*		
Waterloo County (Location #7)	16.1, 21.4, 80.3 16.9, 22.6, 84.6 17.3, 23, 86.3	**5 [0.75**	**3 [0.73]**	**1 [0.58]**	**7 [0.82]**	**12 [0.99]**	**3 [0.66]**	**2 [0.43]**	**1 [0.22]**	**184246 (123.8 min)**	**13,330,355 8,073,200 149,110,000 873.9 sec**
Hamilton County (Location #8)	15.7, 20.9, 78.3 16.5, 22, 82.4, 16.8, 22.4, 84.1	**5 [0.77]**	**3 [0.74]**	**2 [0.30]**	**7 [0.83]**	**13 [0.95]**	**3 [0.68]**	**2 [0.43]**	**1 [0.23]**	**188683 (123.7 min)**	
Niagara County (Location #11)	31.6, 42.1, 157.8 33.2, 44.3, 166.1 33.9, 45.2, 169.5	**3 [0.65]**	**2 [0.56]**	**1 [0.30]**	**4 [0.74]**	**6 [0.97]**	**2 [0.52]**	**1 [0.44]**	**1 [0.12]**	**93804 (118.1 min)**	
Chatham-Kent County (Location #14)	131.4, 175.2, 656.8 138.3, 184.4, 691.4 141.1, 188.1, 705.5	**1 [0.46]**	**1 [0.27]**	**1 [0.07]**	**2 [0.35]**	**4 [0.34]**	**1 [0.24]**	**1 [0.10]**	**1 [0.03]**	**22380 (119.5 min)**	
Essex County (Location #15)	35, 46.7, 175.1 36.9, 49.2, 184.3 37.6, 50.2, 188.1	**2 [0.86]**	**2 [0.50]**	**1 [0.27]**	**3 [0.87]**	**7 [0.88]**	**2 [0.45]**	**2 [0.20]**	**1 [0.11]**	**83879 (132.4 min)**	
Bruce County (Location #1)	62.5, 83.4, 312.6 65.8, 87.8, 329.1 67.2, 89.5, 335.8	**2 [0.50]**	**1 [0.56]**	**1 [0.15]**	**2 [0.75]**	**4 [0.83]**	**1 [0.53]**	**1 [0.23]**	**1 [0.06]**	**47278 (130.7 min)**	
Middlesex County (Location #17)	20.9, 27.9, 104.5 22, 29.3, 110 22.5, 29.9, 112.3	**4 [0.71]**	**2 [0.85]**	**1 [0.46]**	**6 [0.74]**	**11 [0.94]**	**2 [0.77]**	**2 [0.034]**	**1 [0.18]**	**141502 (133.1 min)**	

Table 5.9 Open facilities and resource allocation if handling cost is dominant

If fixed cost is the dominant cost, it can be seen from Table 5.7 that all three heuristics show that the optimum decision is to open one more facility at Middlesex County in addition to the five existing ones. The required resources and the utilization rate is given in Table 5.9. However, if the demand drops to 60%, it would be better not to open any new facilities on top of the five existing facilities.

Facilty Locations	*Interrarrival Time (min)* *NP1, NP2, NP3* *OP1, OP2, OP3* *FP1, FP2, FP3*	**Necessary Recources** *Colonoscopy Doctor(s) [util.]*	*Gastroscopy Doctor(s) [util.]*	*Flexible-S. Doctor(s) [util.]*	*Nurses [util.]*	*PR rooms [util.]*	*Procedure Room(s) type 1 [util.]*	*Procedure Room(s) type 2 [util.]*	*Procedure Room(s) type 3 [util.]*	*Number of Patients (Average Flow Time Operation Patients)*	*Fixed Cost* *Access Cost* *Handling Cost* *CPU time*
Waterloo County (Location #7)	13.5, 18, 67.7 14.2, 19, 71.2 14.5, 19.4, 72.7	**6 [0.74]**	**4 [0.65]**	**1 [0.70]**	**8 [0.85]**	**14 [0.98]**	**4 [0.59]**	**2 [0.51]**	**1 [0.28]**	**218281 (124.8 min)**	**120,552,770** **9,606,300** **14,520,000** **1078.7 sec**
Hamilton County (Location #8)	15.6, 20.9, 78.3 16.5, 22, 82.4 16.8, 22.4, 84.1	**5 [0.76]**	**3 [0.74]**	**1 [0.60]**	**7 [0.83]**	**13 [0.95]**	**3 [0.67]**	**1 [0.43]**	**1 [0.23]**	**188255 (127.1 min)**	
Niagara County (Location #11)	31.6, 42.1, 157.8 33.2, 44.3, 166.1 33.9, 45.2, 169.5	**3 [0.65]**	**2 [0.56]**	**1 [0.29]**	**4 [0.74]**	**6 [0.98]**	**2 [0.52]**	**1 [0.45]**	**1 [0.11]**	**93695 (118.1 min)**	
Chatham-Kent County (Location #14)	131.4, 175.2, 656.8 138.3, 184.4, 691.4 141.1, 188.1, 705.5	**1 [0.46**	**1 [0.28]**	**1 [0.08]**	**2 [0.35]**	**4 [0.35]**	**1 [0.24]**	**1 [0.11]**	**1 [0.03]**	**22496 (120.1 min)**	
Essex County (Location #15)	35, 46.7, 175.1 36.9, 49.2, 184.3 37.6, 50.2, 188.1	**2 [0.85]**	**2 [0.50]**	**1 [0.27]**	**3 [0.88]**	**7 [0.88]**	**2 [0.46]**	**2 [0.20]**	**1 [0.10]**	**84042 (132.2 min)**	
Middlesex County (Location #17)	19.2, 25.6, 95.8 20.2, 26.9, 100.9 20.6, 27.5, 102.9	**4 [0.79]**	**3 [0.61]**	**1 [0.50]**	**6 [0.79]**	**11 [0.95]**	**3 [0.55]**	**1 [0.72]**	**1 [0.19]**	**154281 (128.3 min)**	

Table 5.10 Open facilities and resource allocation if fixed cost is dominant

5.3.1 Sensitivity Analysis

In order to check the sensitivity of the solution provided by heuristics we examined two extreme cases in Case 1, all processing times set to the maximum possible value. In Case 2, all process times altered to its minimum possible value. Each case was inspected with dominant handling, fixed, and access cost respectively. As a result, there is a slight change in the number of open facilities.

As can be seen from Table 5.10, if handling cost is dominant and all processing times are at the maximum value, the number of open facilities remain the same (7 facilities: 5 existing, 2 new). However, if the processing times are at their minimum the number of open facilities drop by one (6 facilities: 5 existing, 1 new), see Table 5.11.

If the dominant fixed cost case, the number of open facilities remains (6 facilities: 5 existing, 1 new). Similarly, the number of open facilities remains the same for the dominant access cost case (17 facilities: 5 existing, 12 new).

In addition, we notice that the performance of the combination of GA+SA is still superior to the other two. As observed before, the dominance of GA+SA is more apparent when access cost is the dominant cost.

k	Costs (%)			CPU (sec)			Best Solution (Order)			Best Solution (Obj. Value)		
	FC	AC	HC	GA	SA	GA+SA	GA	SA	GA+SA	GA	SA	GA+SA
α = 1												
5	5.0	20.6	74.2	2006.3	2006.3	2006.3	-	-	-	206,970,000	206,970,000	206,970,000
6	6.2	13.0	80.8	3979.8	35393.2	32990.5	*	*	*	196,930,000	196,930,000	196,930,000
7	6.9	10.0	83.2	5642.3	34837.7	32744.6	2	3	1	198,350,000	199,160,000	194,820,000
8	7.3	8.3	84.3	7224.3	32056.4	31032.9	3	2	1	202,140,000	196,780,000	195,800,000
9	8.0	6.8	85.2	8704.5	31703.0	30321.0	3	2	1	202,450,000	201,050,000	199,360,000
10	8.4	5.2	86.4	10153.1	29009.7	28711.0	3	2	1	210,150,000	203,700,000	201,825,000
11	9.0	4.2	86.8	11447.8	29116.0	28235.7	3	1	2	213,090,000	209,250,000	211,290,000
12	9.2	3.3	87.5	12585.2	27105.5	26323.7	3	1	2	222,440,000	212,990,000	214,560,000
13	9.6	2.5	87.9	13725.4	27751.9	25725.6	3	1	2	228,270,000	220,120,000	222,660,000
14	10.0	1.9	88.0	14760.8	15611.0	24026.2	2	3	1	230,920,000	233,280,000	228,360,000
15	10.6	1.3	88.1	15753.6	14099.1	22578.3	2	3	1	233,750,000	237,180,000	233,750,000
16	10.8	0.7	88.5	16751.4	13427.4	21981.9	2	3	1	243,760,000	244,700,000	243,760,000
17	11.0	0.3	88.7	17733.5	13872.7	22436.5	*	*	*	253,310,000	253,310,000	253,310,000
18	11.1	0.0	88.9	956.5	956.5	956.5	-	-	-	263,830,596	263,830,596	263,830,596
k	**Costs (%)**			**CPU (sec)**			**Best Solution (Order)**			**Best Solution (Obj. Value)**		
	FC	**AC**	**HC**	**GA**	**SA**	**GA+SA**	**GA**	**SA**	**GA+SA**	**GA**	**SA**	**GA+SA**
α = 1												
5	65.3	25.5	9.2	1989.1	1989.1	1989.1	-	-	-	166,740,000	166,740,000	166,740,000
6	74.7	15.6	9.7	3898.0	36573.4	36559.8	*	*	*	164,240,000	164,240,000	164,240,000
7	79.1	11.4	9.5	5483.0	35728.3	35818.7	2	3	1	173,100,000	176,800,000	173,100,000
8	81.5	9.2	9.3	7027.8	32533.1	33229.9	3	1	2	183,070,000	182,340,000	183,070,000
9	84.0	7.1	8.9	8449.9	30450.0	31530.9	2	3	1	193,400,000	198,340,000	192,080,000
10	85.9	5.3	8.8	9841.4	28180.0	28194.2	2	3	1	206,330,000	206,790,000	206,040,000
11	87.5	4.1	8.4	11061.7	23486.4	20819.4	3	2	1	219,720,000	219,540,000	218,310,000
12	88.5	3.2	8.4	12209.1	22107.5	19508.0	2	3	1	232,140,000	232,440,000	232,140,000
13	89.5	2.3	8.2	13302.1	22366.4	19010.1	2	3	1	244,390,000	245,990,000	243,050,000
14	90.3	1.7	7.9	14286.5	18222.8	15327.6	2	3	1	256,510,000	259,430,000	256,510,000
15	91.3	1.1	7.6	15172.0	17467.7	14051.5	2	3	1	271,690,000	273,240,000	269,960,000
16	91.8	0.6	7.5	15930.9	12411.3	12946.9	3	1	2	286,730,000	284,330,000	286,730,000
17	92.3	0.2	7.5	16657.4	12856.4	13725.2	*	*	*	301,660,000	301,660,000	301,660,000
18	92.5	0.0	7.5	855.1	855.1	855.1	-	-	-	314,681,570	314,681,570	314,681,570
k	**Costs (%)**			**CPU (sec)**			**Best Solution (Order)**			**Best Solution (Obj. Value)**		
	FC	**AC**	**HC**	**GA**	**SA**	**GA+SA**	**GA**	**SA**	**GA+SA**	**GA**	**SA**	**GA+SA**
α = 1												
5	7.2	83.0	9.8	2257.4	2257.4	2257.4	-	-	-	160,140,000	160,140,000	160,140,000
6	11.7	73.6	14.7	4488.3	32134.6	32946.2	*	*	*	108,810,000	108,810,000	108,810,000
7	14.8	67.2	18.0	6512.1	32011.1	32711.6	1	3	1	91,730,000	100,560,000	91,730,000
8	17.9	62.3	19.8	7954.7	30849.6	31392.3	1	3	1	84,231,000	94,510,000	84,231,000
9	21.3	56.2	22.5	9284.5	29983.9	30818.6	2	3	1	76,562,000	89,560,000	76,200,000
10	25.7	45.6	25.8	10548.6	27925.7	29514.8	1	1	1	69,909,000	69,909,000	69,909,000
11	29.0	42.6	28.4	11687.4	27782.9	28441.8	1	3	1	66,105,000	71,100,000	66,105,000
12	32.8	36.6	30.6	12834.8	26542.2	26879.2	1	3	1	62,553,000	65,780,000	62,553,000
13	36.8	29.8	33.4	13927.8	24519.0	26203.4	1	3	1	59,887,000	68,610,000	59,887,000
14	40.6	24.0	35.4	14912.2	13966.5	14505.0	1	3	1	57,746,000	60,340,000	57,746,000
15	45.2	17.2	37.5	15797.7	13659.1	13392.8	1	3	1	54,852,000	55,237,000	54,852,000
16	48.9	10.3	40.8	16556.6	13203.7	12648.8	1	2	1	54,101,000	54,759,000	54,101,000
17	52.9	4.1	43.1	17283.1	13616.3	13434.3	*	*	*	52,651,000	52,651,000	52,651,000
18	55.4	0.0	44.6	738.3	738.3	738.3	-	-	-	52,689,000	52,689,000	52,689,000

Table 5.11 Heuristic results when all process times are at the maximum level

k	Costs (%)			CPU (sec)			Best Solution (Order)			Best Solution (Obj. Value)		
	FC	AC	HC	GA	SA	GA+SA	GA	SA	GA+SA	GA	SA	GA+SA
α = 1												
5	6.1	25.4	68.5	1850.1	1850.1	1850.1	-	-	-	167,620,000	167,620,000	167,620,000
6	7.2	16.0	76.8	3509.2	32184.0	29921.0	*	*	*	160,500,000	160,500,000	160,500,000
7	8.0	12.2	79.7	4879.9	30003.4	27758.0	2	3	1	161,590,000	163,640,000	161,240,000
8	8.6	10.1	81.3	6126.1	28171.2	27032.2	3	2	1	166,120,000	160,930,000	165,100,000
9	9.2	8.1	82.7	7328.8	26820.6	25495.0	3	2	1	169,940,000	167,760,000	167,180,000
10	9.7	6.2	84.1	8507.6	24394.0	24113.0	2	1	2	174,500,000	173,580,000	174,440,000
11	10.3	5.0	84.7	9605.5	26140.2	23764.3	2	1	2	180,490,000	185,140,000	180,390,000
12	10.6	3.9	85.6	10563.3	24551.0	22455.5	3	2	1	190,050,000	189,650,000	185,290,000
13	10.8	2.9	86.3	11498.7	15192.4	22945.8	2	1	2	199,040,000	195,790,000	199,040,000
14	11.1	2.2	86.7	12320.0	15180.0	19309.5	1	3	2	205,250,000	207,740,000	205,250,000
15	11.5	1.4	87.1	13050.9	13683.0	19881.5	2	1	2	212,090,000	211,650,000	212,090,000
16	11.6	0.8	87.6	13571.3	14384.1	18483.8	3	1	2	221,920,000	218,600,000	219,600,000
17	11.9	0.3	87.8	14025.5			*	*	*	229,350,000	229,350,000	229,350,000
18	12.0	0.0	88.0	434.1	434.1	434.1	-	-	-	239,920,000	239,920,000	239,920,000
k	Costs (%)			CPU (sec)			Best Solution (Order)			Best Solution (Obj. Value)		
	FC	AC	HC	GA	SA	GA+SA	GA	SA	GA+SA	GA	SA	GA+SA
α = 1												
5	65.6	27.1	7.3	1694.0	1694.0	1694.0	-	-	-	156,850,000	156,850,000	156,850,000
6	75.4	16.6	8.0	3325.7	24425.3	26082.6	*	*	*	154,150,000	154,150,000	154,150,000
7	79.9	12.1	7.9	4689.8	22197.2	24626.6	1	1	1	162,600,000	162,600,000	162,600,000
8	82.5	9.7	7.8	5939.3	20559.1	23864.0	2	3	1	173,020,000	178,210,000	171,620,000
9	84.8	7.5	7.7	6826.5	19783.9	24214.0	2	3	1	183,700,000	185,230,000	182,680,000
10	86.9	5.6	7.5	7683.8	17736.8	21442.1	3	2	1	194,920,000	194,780,000	193,900,000
11	88.4	4.3	7.3	8493.3	18618.9	19442.2	2	3	1	210,010,000	211,160,000	208,990,000
12	89.5	3.3	7.2	9286.3	17008.8	18859.0	2	3	1	224,600,000	224,770,000	223,490,000
13	90.3	2.4	7.3	10099.7	15553.1	18360.8	1	3	1	236,390,000	241,210,000	236,390,000
14	91.1	1.8	7.1	10826.1	15375.2	16732.5	3	1	2	249,900,000	249,070,000	249,510,000
15	91.9	1.1	7.0	11558.4	15564.7	16278.4	1	3	1	264,090,000	264,870,000	264,090,000
16	92.4	0.6	7.0	12289.1	14400.9	15920.6	2	1	2	279,120,000	278,990,000	279,120,000
17	93.0	0.2	6.8	13008.9	13101.9	14653.5	*	*	*	294,010,000	294,010,000	294,010,000
18	93.2	0.0	6.8	720.4	720.4	720.4	-	-	-	308,195,300	308,195,300	308,195,300
k	Costs (%)			CPU (sec)			Best Solution (Order)			Best Solution (Obj. Value)		
	FC	AC	HC	GA	SA	GA+SA	GA	SA	GA+SA	GA	SA	GA+SA
α = 1												
5	6.7	86.0	7.4	1570.1	1570.1	1570.1	-	-	-	154,770,000	154,770,000	154,770,000
6	11.2	76.9	11.8	1487.6	25827.9	27718.8	*	*	*	104,080,000	104,080,000	104,080,000
7	15.0	70.3	14.7	1300.1	25571.6	27295.5	2	3	1	87,677,700	96,470,000	87,400,000
8	17.8	65.4	16.8	1209.7	25156.8	26971.0	2	3	1	80,214,000	90,350,000	80,070,000
9	21.4	59.2	19.3	1033.7	23846.8	24096.0	2	3	1	72,686,000	83,960,000	72,580,000
10	25.9	51.8	22.4	1135.2	21268.8	23365.8	2	2	1	65,604,000	65,604,000	65,460,000
11	30.0	45.4	24.6	1069.9	22332.7	22358.2	2	3	1	62,045,000	66,790,000	61,900,000
12	33.9	38.6	27.4	995.5	20299.3	21946.5	2	3	1	59,287,000	62,520,000	59,150,000
13	38.0	31.6	30.4	966.3	18582.4	21534.7	1	3	1	56,465,000	65,247,000	56,465,000
14	41.9	25.4	32.6	907.6	18747.7	19846.3	2	3	1	54,523,000	58,431,000	54,272,000
15	46.5	18.1	35.4	829.5	17394.4	19201.1	2	3	1	52,227,000	53,141,000	52,086,000
16	50.8	11.0	38.3	849.3	16889.5	19069.5	2	3	1	50,845,000	51,016,000	50,807,000
17	55.1	4.3	40.6	792.9	16731.1	18547.2	*	*	*	49,635,000	49,635,000	49,635,000
18	57.8	0.0	42.2	437.1	437.1	437.1	-	-	-	49,991,151	49,991,151	49,991,151

Table 5.12 Heuristic results when all process times are at the minimum level

Chapter 6

Conclusion

In this project, we developed a simulation model to estimate the number of personnel and resource requirements to supply the demand for endoscopy screening while keeping the waiting times under a certain threshold. We proposed simulation optimization approaches to decide where the new clinics should be open based on facility opening, handling, and unit access costs.

In this sense, three heuristics were proposed to determine the number of facilities needed and where to locate them. The model was applied in Western Ontario with a population of 3.5 million and 18 counties. The performance of the proposed simulation-optimization model was tested under different circumstances and parameter settings each method performs best was specified.

Endoscopy screening is crucial for early detection of gastrointestinal cancers, and is key to treat properly early cases. In this study, it becomes apparent that preventive screening of digestive system cancer is not popular in Canada, and that is one of prime reasons for high cancer rates in Ontario. As people become more aware of the situation over time, the demand for endoscopy screening will increase, similar to what has happened in the United States. As a consequence, the current facilities will become unable to cover all demand. The proposed methodology may provide a realistic framework to aid public health authorities to plan and analyze capacity expansion decisions.

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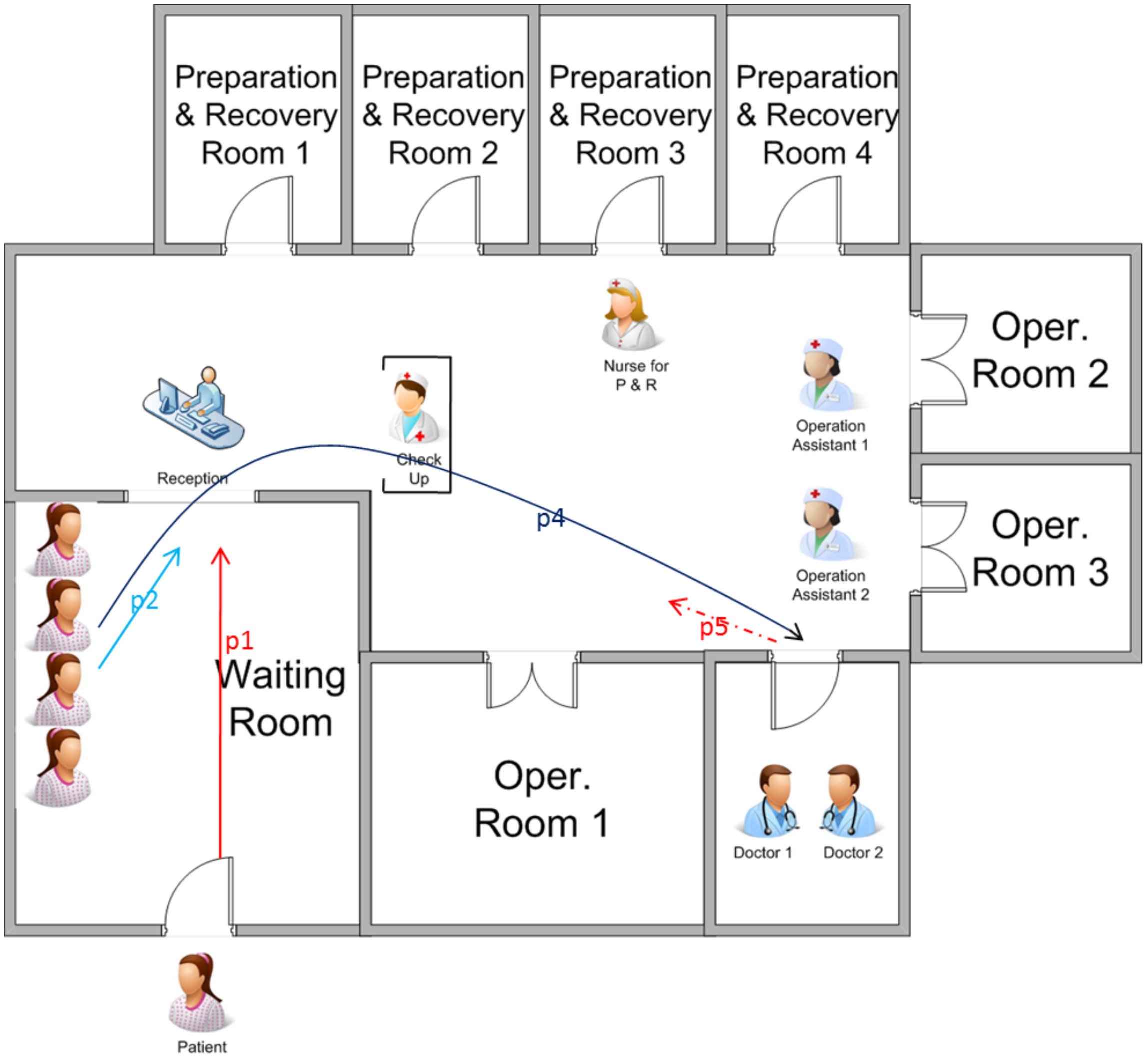
Appendix A

Distances	Bruce	Grey	Dufferin	Wellington	Huron	Perth	Waterloo	Hamilton	Brant	Haldmiand	Niagara	Nortfolk	Elgin	Chatham-Kent	Essex	Lambton	Middelsex	Oxford
Bruce	0	82.7	93.3	70.4	86	84.8	103	146	155	191	209	197	213	247	318	165	157	139
Grey		0	69.1	90.5	172	148	131	169	185	222	223	225	254	344	398	267	231	167
Dufferin			0	55.5	152	121	83.4	111	123	154	162	172	199	289	342	237	196	130
Wellington				0	129	70.4	45.5	84.2	92.4	129	143	136	156	247	300	186	146	82
Huron					0	61.3	112	153	157	193	229	163	147	161	224	82.1	95	103
Perth						0	54.1	106	84.9	144	179	116	112	180	250	130	89.7	60.9
Waterloo							0	59.5	62.3	102	131	89.3	122	213	266	163	122	78.9
Hamilton								0	24.7	50.1	69.7	81.7	133	223	277	196	140	67
Brant									0	44.1	86.2	58.6	103	202	256	175	119	51.2
Haldmiand										0	73.1	50.8	110	230	293	212	156	85.3
Niagara											0	120	195	286	339	258	202	135
Norfolk												0	61	186	247	165	108	56.7
Elgin													0	128	181	120	61.3	74.3
Chatham-Kent														0	59.4	85.7	90.1	165
Essex															0	154	161	218
Lambton																0	62.1	126
Middlexex																	0	77
Oxford																		0

Table 6.1 Distance between Western Ontario counties



Procedure for
New Patient:

✓**p1** - Take the paperwork from Reception

✓**d1** - spent time for filling the paperwork at Waiting Room

✓**p2** - Deliver the paperwork to Reception

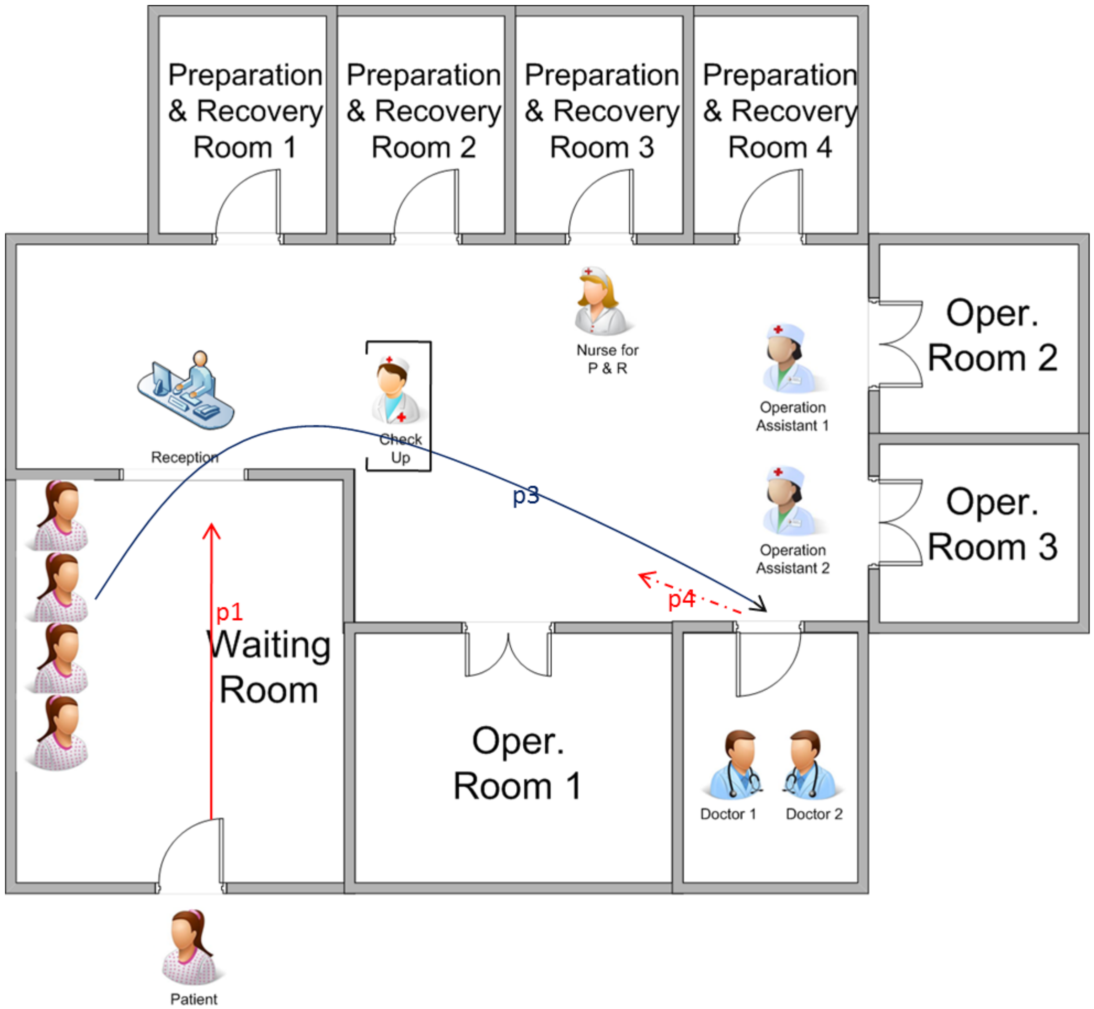
✓**q1** - Wait at queue at "Waiting Room" for Doctor

✓**p3** – When patient tern comes, Doctor spent some time reading patient file before meeting the patient

✓**p4** - Go to meeting room for Consulting

✓**p5** - Leave Hospital

Figure 6.1 Layout based process flow of incoming new patient



Procedure for
Follow-up Patient:

✓**p1** - Inform Reception for arrival
✓**q1** - Wait in Waiting Room for available Doctor
✓**p2 – Doctor spent some time for checking patient file**
✓**p3** – Meet with the Doctor
✓**p4** - Leave Hospital

Figure 6.2 Layout based process flow of incoming follow-up patient

Appendix B

Pseudo Code of Simulation Function

Abbreviations

_1	->	Refer to Colonoscopy
_2	->	Refer to Gastroscopy
_3	->	Refer to Flexible Sigmoidoscopy
M	->	Sufficiently Big Number
NP	->	New Patients waiting for Consulting
FP	->	Follow-up Patient waiting for Consulting
OP	->	Operation Patient waiting for Check-up
WP	->	Operation Patient completed Check-up and waiting for Preparation
WOP	->	Operation Patient completed Preparation and waiting for Procedure
W_N	->	Operation Patient completed Procedure waiting for Recovery at PR room
W	->	Waiting time upper bound

Function Input

(Register Time, Check-up time, Consulting time of New Patient type 1 & type 2 & type 3, Preparation time, Pre-Procedure & Procedure & Post-Procedure times of type 1 & type 2 & type 3 patients, Consulting time of Follow-up Patient type 1 & type 2 & type 3, Recovery time for type 1& type 2 & type 3 patients, Final check-up time, Inter-arrival time of New Patients & Operation Patients & Follow-up patients of type 1 & type 2 & type 3, Run Time, Warm-up Time)

Generate and store sufficient amount of random process times of 20 different distribution function to be used iteratively in single simulation

Set number of type 1 Doctor in clinic to one

Set number of type 2 Doctor in clinic to one

Set number of type 3 Doctor in clinic to one

Set number of Nurses in clinic to two

Set number of PR rooms in clinic to four

Set number of type 1 Procedure rooms to one

Set number of type 2 Procedure rooms to one

Set number of type 3 Procedure rooms to one

Set available type 1 doctors array to zeros

Set available type 2 doctors array to zeros

Set available type 3 doctors array to zeros

Set available time nurse array to zeros

Set available time type 1 procedure rooms to zeros

Set available time type 2 procedure rooms to zeros

Set available time type 3 procedure rooms to zeros

Generate and store type 1 New Patients arrival times to clinic

Generate and store type 2 New Patients arrival times to clinic

Generate and store type 3 New Patients arrival times to clinic

Generate and store type 1 Follow-up Patients arrival times to clinic

Generate and store type 2 Follow-up Patients arrival times to clinic

Generate and store type 3 Follow-up Patients arrival times to clinic

Generate and store type 1 Operation Patients arrival times to clinic

Generate and store type 2 Operation Patients arrival times to clinic

Generate and store type 3 Operation Patients arrival times to clinic

Set test_begin to zero

Set tested array to array of zeros 1x8

```
Set improve to zero
while (improve=0)
Set receive type 1 patients to 1
while received type 1 patients is 1 or mean check up time of any type of patient > W
Set indexes of NP_1, NP_2, NP_3, FP_1, FP_2, FP_3, OP_1, OP_2, OP_3 to 1
Set check-up queue to zero
Set WP_1, WP_2, WP_3, WOP_1, WOP_2, WOP_3, W_N_1, W_N_2, W_N_3 to array of 1
element (M)
Add big M at the end of NP_1, NP_2, NP_3, FP_1, FP_2, FP_3, OP_1, OP_2, OP_3 queue
arrays
Set received type 1, type 2, type 3 patients to 1
Set pr_index_1 to 1;
Set pr_index_2 to 1;
Set all type of doctors busy time to zero
Set nurses busy time to zero
Set PR rooms busy time to zero
Set all type of procedure rooms busy time to zero
Set previous check up time to zero
 while first process < Run Time
        Store "EVENT LIST", the last served NP_1, NP_2, NP_3, FP_1, FP_2, FP_3, OP_1,
OP_2, OP_3,    WP_1,  WP_2, WP_3, WOP_1, WOP_2, WOP_3, W_N_1, W_N_2, W_N_3
        Update the number of occupied PR room
if occupied PR room >= num of PR room
        Replace WP_1,         WP_2, WP_3 in "EVENT LIST" with M
end
if patient in check_up queue=1
        Replace OP_1, OP_2, OP_3 in "EVENT LIST"  with M
end
```

```
Find first patient among NP_1, F_1, OP_1 and store its index number as "stored_index_1"
Find first patient among NP_2, F_2, OP_2 and store its index number as "stored_index_2"
Find first patient among NP_3, F_3, OP_3 and store its index number as "stored_index_3"
if OP_1 is first and length(WOP_1)>1
        Replace NP_1, FP_1 in "EVENT LIST" by M
end
if OP_2 is first and length(WOP_2)>1
        Replace NP_2, FP_2 in "EVENT LIST" by M
end
if OP_3 is first and length(WOP_3)>1
        Replace NP_3 ,FP_3 in "EVENT LIST" by M
        end
        Find first process and its index from EVENT LIST;
if index=1
        if  stored_index_1 = 3 and length (WOP_1) > 1 and number of type 1 doctor > 1
                Find max time between NP_1 and second available type 1 doctor
                Update type 1 doctor available time
                Update NP_1 index (increase by 1)
        else
                Find max time between NP_1 and first available type 1 doctor
                Update type 1 doctor available time
                Update NP_1 index (increase by 1)
        end
                if first process > Warm up period
                        Store NP type 1 waiting time before in Consulting queue
                        Store doctor type 1 busy time
                end
end
```

```
if index=2
        if  stored_index_2 = 3 and length (WOP_2) > 1 and number of type 2 doctor > 1
                Find max time between NP_2 and second available type 2 doctor
                Update type 2 doctor available time
                Update NP_2 index (increase by 1)
        else
                Find max time between NP_2 and first available type 2 doctor
                Update type 2 doctor available time
                Update NP_2 index (increase by 1)
        end
                if first process > Warm up period
                        Store NP type 2 waiting time before in Consulting queue
                        Store doctor type 2 busy time
                end
end

if index=3
        if  stored_index_3= 3 and length (WOP_3) > 1 and number of type 3 doctor > 1
                Find max time between NP_3 and second available type 3 doctor
                Update type 3 doctor available time
                Update NP_3 index (increase by 1)
        else
                Find max time between NP_3 and first available type 3 doctor
                Update type 3 doctor available time
                Update NP_3 index (increase by 1)
        end
                if first process > Warm up period
                        Store NP type 3 waiting time before in Consulting queue
```

```
                Store doctor type 3 busy time
            end
end
if index=4
        if  stored_index_1= 3 and length (WOP_1) > 1 and number of type 1 doctor > 1
                Find max time between FP_1 and second available type 1 doctor
                Update type 1 doctor available time
                Update FP_1 index (increase by 1)
        else
Set consulting start time to max time between FP_1 and first available type 1 doctor
Set type 1 doctor available time to consulting start time + random consulting duration
Update FP_1 index (increase by 1)
        end
            if first process > Warm up period
                Store FP type 1 waiting time before in Consulting queue
                Store doctor type 1 busy time
            end
end
if index=5
        if  stored_index_2= 3 and length (WOP_2) > 1 and number of type 2 doctor > 1
                Find max time between FP_2 and second available type 2 doctor
                Update type 2 doctor available time
                Update FP_2 index (increase by 1)
        else
Set consulting start time to max time between FP_2 and first available type 2 doctor
Set type 2 doctor available time to consulting start time + random consulting duration
Update FP_2 index (increase by 1)
        end
```

```
                if first process > Warm up period
                        Store FP type 2 waiting time before in Consulting queue
                        Store doctor type 2 busy time
                end
end
if index=6
        if  stored_index_3= 3 and length (WOP_3) > 1 and number of type 3 doctor > 1
                Find max time between FP_3 and second available type 3 doctor
                Update type 3 doctor available time
                Update FP_3 index (increase by 1)
        else
Set consulting start time to max time between FP_3 and first available type 3 doctor
Set type 3 doctor available time to consulting start time + random consulting duration
Update FP_3 index (increase by 1)
        end
                if first process > Warm up period
                        Store FP type 3 waiting time before in Consulting queue
                        Store doctor type 3 busy time
                end
end
if index=7
Set check-up start time to maximum value among:
        a) First available nurse
        b) First OP_1 patient
        c) "Previous check-up completion time
Set "Previous check-up" completion time to check-up start time + random check-up
duration
Update nurse available time
```

Update OP_1 index (increase by 1)

Update WP_1 by adding last check-up completion time to WP_1 array

Sort WP_1 queue

    if first process > Warm up period

        Store amount of time patient waited for check-up

        Count received type 1 patient

    end

end

if index=8

Set check-up start time to maximum value among:

    a) First available nurse

    b) First OP_2 patient

    c) "Previous check-up completion time

Set "Previous check-up" completion time to check-up start time + random check-up duration

Update nurse available time

Update OP_2 index (increase by 1)

Update WP_2 by adding last check-up completion time to WP_2 array

Sort WP_2 queue

    if first process > Warm up period

        Store amount of time patient waited for check-up

        Count received type 2 patient

    end

end

if index=9

  Set check-up start time to maximum value among:

    a) First available nurse

    b) First OP_3 patient

```
        c) "Previous check-up completion time
Set "Previous check-up" completion time to check-up start time + random check-up
duration
Update nurse available time
Update OP_3 index (increase by 1)
Update WP_3 by adding last check-up completion time to WP_3 array
Sort WP_3 queue
        if first process > Warm up period
            Store amount of time patient waited for check-up
            Count received type 3 patient
        end
end

if index=10
    Set Preparation start time to maximum value among:
        a) First available nurse
        b) WP_1
Set available nurse time to Preparation start time + random preparation duration
Update check-up queue (decrease by 1)
        if first process > Warm up period
            Store amount of time patient waited for preparation
            Store nurse busy time
        end
    Update PR_Room_Enter (pr_index_1)
    Update pr_index_1 (increase by 1)
    Set first available_pr_room time to M
    Update WOP_1 by adding last preparation completion time to WOP_1 array
    Sort WOP_1 queue
```

Clear first patient at WP_1 queue

end

if index=11

Set Preparation start time to maximum value among:

a) First available nurse

b) WP_2

Set available nurse time to Preparation start time + random preparation duration

Update check-up queue (decrease by 1)

if first process > Warm up period

Store amount of time patient waited for preparation

Store nurse busy time

end

Update PR_Room_Enter (pr_index_1)

Update pr_index_1 (increase by 1)

Set first available_pr_room time to M

Update WOP_2 by adding last preparation completion time to WOP_2 array

Sort WOP_2 queue

Clear first patient at WP_2 queue

end

if index=12

Set Preparation start time to maximum value among:

a) First available nurse

b) WP_3

Set available nurse time to Preparation start time + random preparation duration

Update check-up queue (decrease by 1)

if first process > Warm up period

Store amount of time patient waited for preparation

Store nurse busy time

end

Update PR_Room_Enter (pr_index_1)

Update pr_index_1 (increase by 1)

Set first available_pr_room time to M

Update WOP_3 by adding last preparation completion time to WOP_2 array

Sort WOP_3

Clear first patient at WP_3

end

if index=13

Set type 1 Procedure start time to maximum value among:

a) First available nurse

b) First available type 1 doctor

c) First available type 1 procedure room

d) First patient in WOP_1 queue

Set Procedure end time to type 1 Procedure start time + random type 1 procedure duration

Update available nurse

Update available type 1 doctor

Update available type 1 procedure room

if first process > Warm up period

Store amount of time patient waited for procedure

Store nurse busy time

Store type 1 doctor busy time

Store type 1 procedure room

end

Clear first patient at WOP_1 queue

Set Recovery completion time to procedure end time + random type 1 recovery duration

Update W_N_1 by adding last recovery completion time to W_N_1 array

Sort W_N_1 queue
end
if index=14
    Set type 2 Procedure start time to maximum value among:
        a) First available nurse
        b) First available type 2 doctor
        c) First available type 2 procedure room
        d) First patient in WOP_2 queue
Set Procedure end time to type 2 Procedure start time + random type 2 procedure duration
Update available nurse
Update available type 2 doctor
Update available type 2 procedure room
Update
        if first process > Warm up period
            Store amount of time patient waited for procedure
            Store nurse busy time
            Store type 2 doctor busy time
            Store type 2 procedure room
        end
    Clear first patient at WOP_2 queue
Set Recovery completion time to procedure end time + random type 2 recovery duration
Update W_N_2 by adding last recovery completion time to W_N_2 array
Sort W_N_2 queue
end
if index=15
    Set type 3 Procedure start time to maximum value among:
        a) First available nurse

b) First available type 3 doctor

c) First available type 3 procedure room

d) First patient in WOP_3 queue

Set Procedure end time to type 3 Procedure start time + random type 3 Procedure duration

Update available nurse

Update available type 3 doctor

Update available type 3 procedure room

Update

if first process > Warm up period

Store amount of time patient waited for procedure

Store nurse busy time

Store type 3 doctor busy time

Store type 3 procedure room

end

Clear first patient at WOP_3 queue

Set Recovery completion time to procedure end time + random type 2 recovery duration

Update W_N_3 by adding last recovery completion time to W_N_3 array

Sort W_N_3 queue

end

if index=16

Set "Final Check-up" start time to maximum value among:

a) First available nurse

b) First patient in W_N_1 queue

Set "Final Check-up" end time to "Final Check-up" start time + random check-up time

Update available nurse

if first process > Warm up period

Store amount of time patient waited for "Final Check-up" process

```
                    Store nurse busy time
                end
        Update PR_Room_Leave (pr_index_2)
        Update pr_index_2 (increase by 1)

        Clear first patient at W_N_1 queue
        Update available_pr_room time, change the value from M to 0
end
if index=17
        Set "Final Check-up" start time to maximum value among:
                a) First available nurse
                b) First patient in W_N_2 queue
Set "Final Check-up" end time to "Final Check-up" start time + random check-up time
Update available nurse
                if first process > Warm up period
                    Store amount of time patient waited for "Final Check-up" process
                    Store nurse busy time
                end
        Update PR_Room_Leave (pr_index_2)
        Update pr_index_2 (increase by 1)
        Clear first patient at W_N_2 queue
        Update available_pr_room time, change the value from M to 0
end
if index=18
        Set "Final Check-up" start time to maximum value among:
                a) First available nurse
                b) First patient in W_N_3 queue
Set "Final Check-up" end time to "Final Check-up" start time + random check-up time
```

```
Update available nurse
        if first process > Warm up period
            Store amount of time patient waited for "Final Check-up" process
            Store nurse busy time
        end
    Update PR_Room_Leave (pr_index_2)
    Update pr_index_2 (increase by 1)
    Clear first patient at W_N_3 queue
    Update available_pr_room time, change the value from M to 0
end
end
if one of conditions below is true:
    a) received type 1 or type 2 or type 3 patients is equal to 1
    b) mean check-up time of type 1-2-3 patient > W
        if test_begin=1
            Update tested array (Set corresponding index to 1)
            Update resources (increase the last resource decreased)
        end
        Set run_terminated to 1
        break the while loop
    end
if received type 1 or type 2 or type 3 patients is equal to 1
    print "Waiting times are congested"
    Increase number of all types of doctor by 1
    Increase number of PR rooms by 1
    Increase number of all types of procedure rooms by 1
    Set available type 1 doctors array to zeros
    Set available type 2 doctors array to zeros
```

Set available type 3 doctors array to zeros

Set available time nurse array to zeros

Set available time type 1 procedure rooms to zeros

Set available time type 2 procedure rooms to zeros

Set available time type 3 procedure rooms to zeros

else

if mean check-up time of type 1 patient > W

Find minimum among:

a) Utilization of type 1 doctor = type 1 doctor busy time /(number of type 1 doctor * (Run_Time - Warm_up_period))

b) Utilization of procedure room type 1 = procedure room type 1 busy time /(number of type 1 Procedure rooms * (Run_Time - Warm_up_period))

c) Utilization of nurses = nurse busy time / (number of nurses * (Run_Time - Warm_up_period))

d) Utilization of PR rooms = sum(pr_room_leave(1:(pr_index_2-1)) -pr_room_enter(1:(pr_index_2-1))) / (number of pr rooms * (Run_Time - Warm_up_period))

if a is min

Increase number of type 1 doctor by 1

else if b is min

increase number of procedure room type 1 by 1

else if c is min

Increase number of PR rooms by 1

end

else if mean check-up time of type 2 patient > W

Find minimum among:

a) Utilization of type 2 doctor = type 2 doctor busy time /(number of type 2 doctor * (Run_Time - Warm_up_period))

b) Utilization of procedure room type 2 = procedure room type 2 busy time /(number of type 2 Procedure rooms * (Run_Time - Warm_up_period))

c) Utilization of nurses = nurse busy time / (number of nurses * (Run_Time - Warm_up_period))

d) Utilization of PR rooms = sum(pr_room_leave(1:(pr_index_2-1)) -pr_room_enter(1:(pr_index_2-1))) / (number of pr rooms * (Run_Time - Warm_up_period))

```
        if a is min
                Increase number of type 2 doctor by 1
        else if b is min
                increase number of procedure room type 2 by 1
        else if c is min
                Increase number of PR rooms by 1
        end
else if mean check-up time of type 3 patient > W
```

Find minimum among:

a) Utilization of type 3 doctor = type 3 doctor busy time /(number of type 3 doctor * (Run_Time - Warm_up_period))

b) Utilization of procedure room type 3 = procedure room type 3 busy time /(number of type 3 Procedure rooms * (Run_Time - Warm_up_period))

c) Utilization of nurses = nurse busy time / (number of nurses * (Run_Time - Warm_up_period))

d) Utilization of PR rooms = sum(pr_room_leave(1:(pr_index_2-1)) -pr_room_enter(1:(pr_index_2-1))) / (number of pr rooms * (Run_Time -Warm_up_period))

```
        if a is min
                Increase number of type 3 doctor by 1
        else if b is min
                increase number of procedure room type 3 by 1
        else if c is min
```

Increase number of PR rooms by 1

end

end

Increase number of all types of doctor by 1

Increase number of PR rooms by 1

Increase number of all types of procedure rooms by 1

Set available type 1 doctors array to zeros

Set available type 2 doctors array to zeros

Set available type 3 doctors array to zeros

Set available time nurse array to zeros

Set available time type 1 procedure rooms to zeros

Set available time type 2 procedure rooms to zeros

Set available time type 3 procedure rooms to zeros

end (while received type 1...)

Print number of all resources: type 1-2-3 doctor, nurses, PR Rooms, type 1-2-3 Procedure rooms

end

Print utilization of all resources

if run terminated = 0

Calculate all resources utilization by formulation above

Store utilization

else

Set utilization to stored utilization

end

if test begin = 0

Print resources (Last updated resources before decreasing)

end

if test_begin=1 & improve = 1

```
        Print resources
        Print utilization
end
Set test_begin to 1
if one resources is reached its lower bound
        Set corresponding element in tested array to 1
end
Set utilization_test to utilization + 10*tested
Find utilization value and utilization index of min utilzation_test
if min utilization level > 10
        Set tested to ones of 1x8
        Set improve to 1
else
        Update the resource at min utilization index (decrease by 1)
        Set available type 1 doctors array to zeros
        Set available type 2 doctors array to zeros
        Set available type 3 doctors array to zeros
        Set available time nurse array to zeros
        Set available time type 1 procedure rooms to zeros
        Set available time type 2 procedure rooms to zeros
        Set available time type 3 procedure rooms to zeros
end
end (while improve = 0)
Function Output
(Wait_OP_1, Wait_OP_2, Wait_OP_3, Wait_WP_1, Wait_WP_2, Wait_WP_3,
Wait_WOP_1, Wait_WOP_2, Wait_WOP_3, Wait_W_N_1, Wait_W_N_2, Wait_W_N_3,
Number of generated patients, Number of all Doctors type 1, Doctor type 2, Doctors type
3, Nurses, PR rooms, Op. room type 1, Op. room type 2, Op. room type 3)
```